FINAL
02 APRIL 1996

FY95 LIMITED ENERGY STUDY
AREA B NITRIC ACID PRODUCTION FACILITIES

HOLSTON ARMY AMMUNITION PLANT
KINGSPORT, TENNESSEE

U.S. ARMY CORPS OF ENGINEERS
MOBILE DISTRICT

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AESE PROJECT NO.: 95094-00

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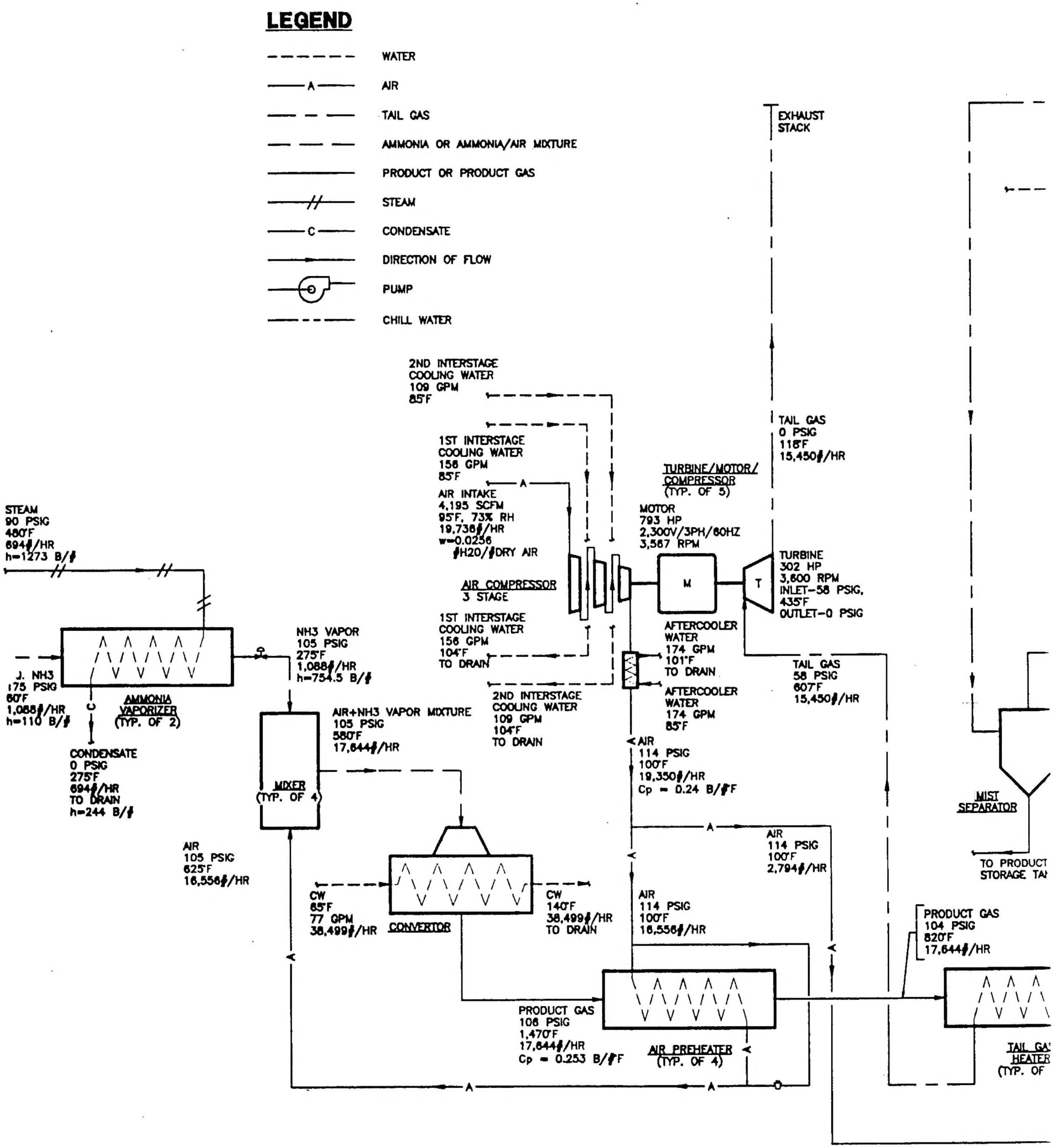
Title Page
Table of Contents
Extracted to go with
Executive Summary
4/19/96

Executive Summary
Extracted 4/19/96
In EN-DM files

History

Holston Army Ammunition Plant (HAAP) in Kingsport, Tennessee, manufactures explosives from raw materials. The facility comprises two separate areas designated Area "A" and Area "B".

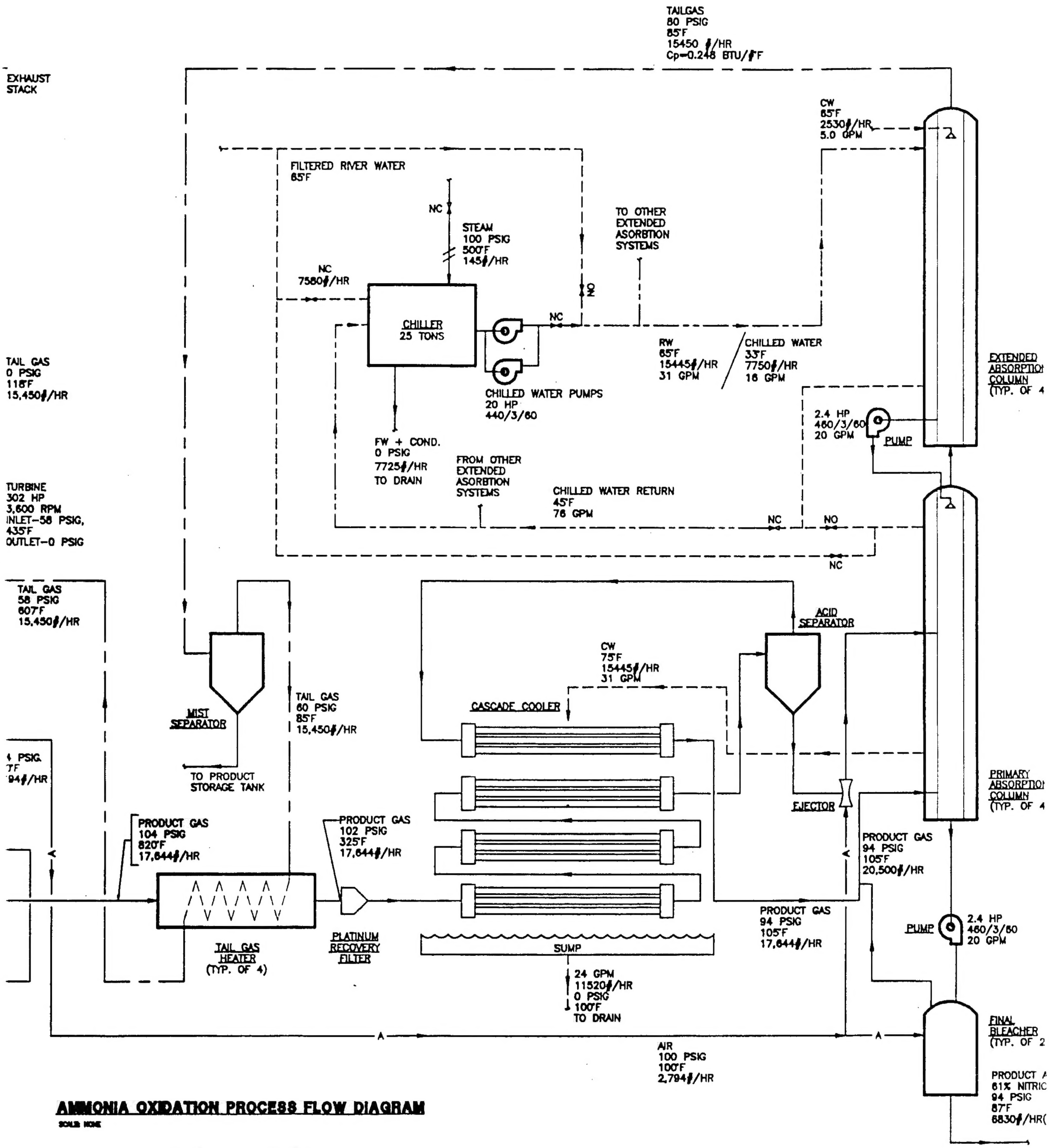
At Area "B", Nitric Acid production facilities located in Building 302 include energy intensive AOP lines from which dilute nitric acid is obtained. The original chemical and mechanical equipment was placed in service in 1942, employing a process invented in 1935. Significant modifications have occurred over the extended life of the systems, and the current configuration is shown schematically in Figure 1.



AMMONIA OXIDATION PRO

SCALE: NONE

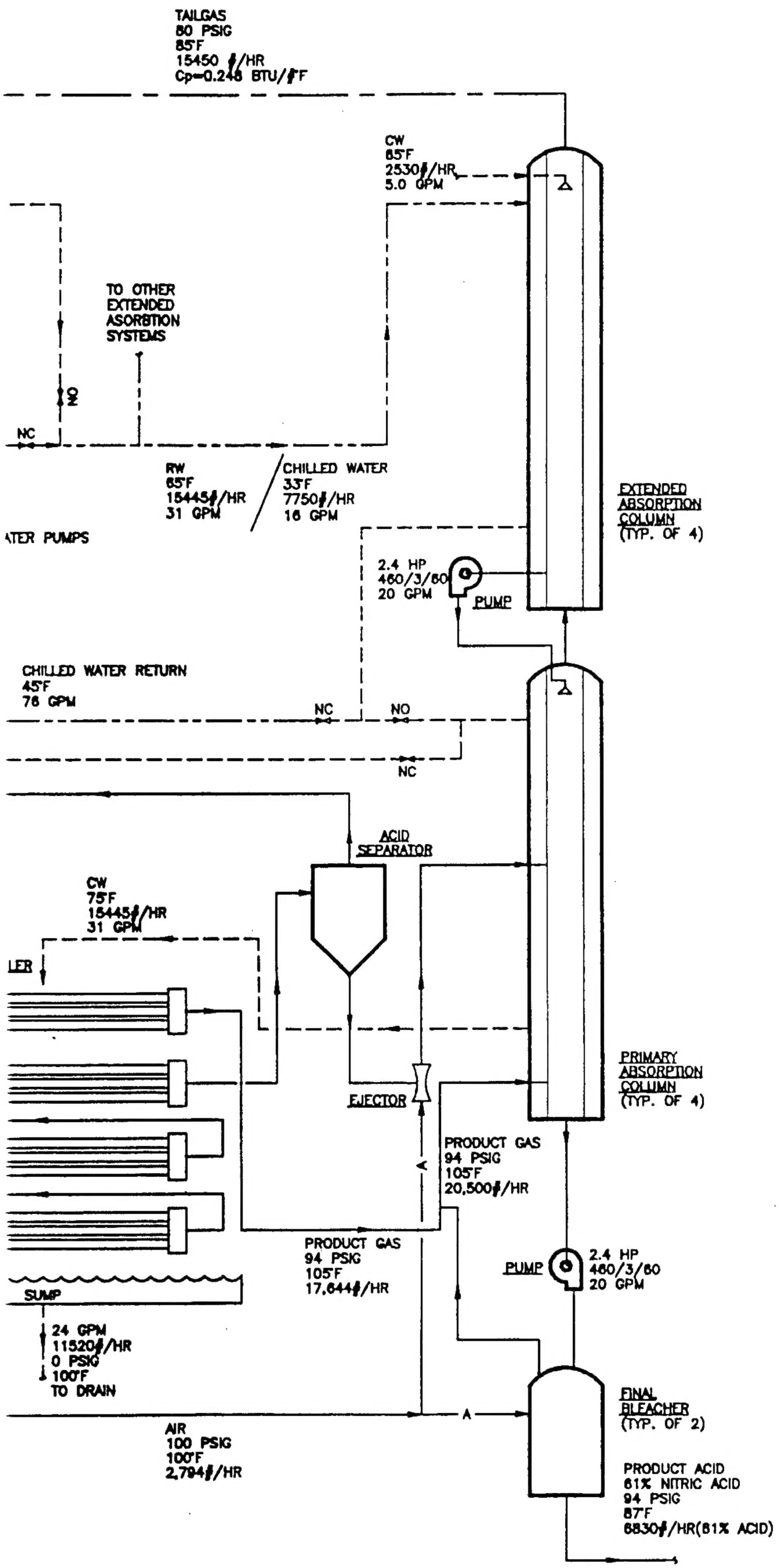
EXISTING S



AMMONIA OXIDATION PROCESS FLOW DIAGRAM

SCALE: NONE

EXISTING SYSTEM


TAILGAS
80 PSIG
85°F
15450 #/HR
Cp=0.248 BTU/#°F
CW
85°F
2530#/HR
5.0 GPM
TO OTHER EXTENDED ASORBTION SYSTEMS
NO
NC
RW
65°F
154454/HR
31 GPM
CHILLED WATER
33°F
7750#/HR
16 GPM
ATER PUMPS
EXTENDED ABSORPTION COLUMN (TYP. OF 4)
2.4 HP
460/3/60
20 GPM
PUMP
CHILLED WATER RETURN
45°F
76 GPM
NC
NO
NC
ACID SEPARATOR
CW
75°F
15445#/HR
31 GPM
LER
EJECTOR
PRIMARY ABSORPTION COLUMN (TYP. OF 4)
PRODUCT GAS
94 PSIG
105°F
20,500#/HR
A
PRODUCT GAS
94 PSIG
105°F
17,644#/HR
PUMP
2.4 HP
460/3/60
20 GPM
SUMP
24 GPM
11520#/HR
0 PSIG
100°F
TO DRAIN
A
FINAL BLEACHER (TYP. OF 2)
AIR
100 PSIG
100°F
2,794#/HR
PRODUCT ACID
61% NITRIC ACID
94 PSIG
87°F
6830#/HR(61% ACID)

3

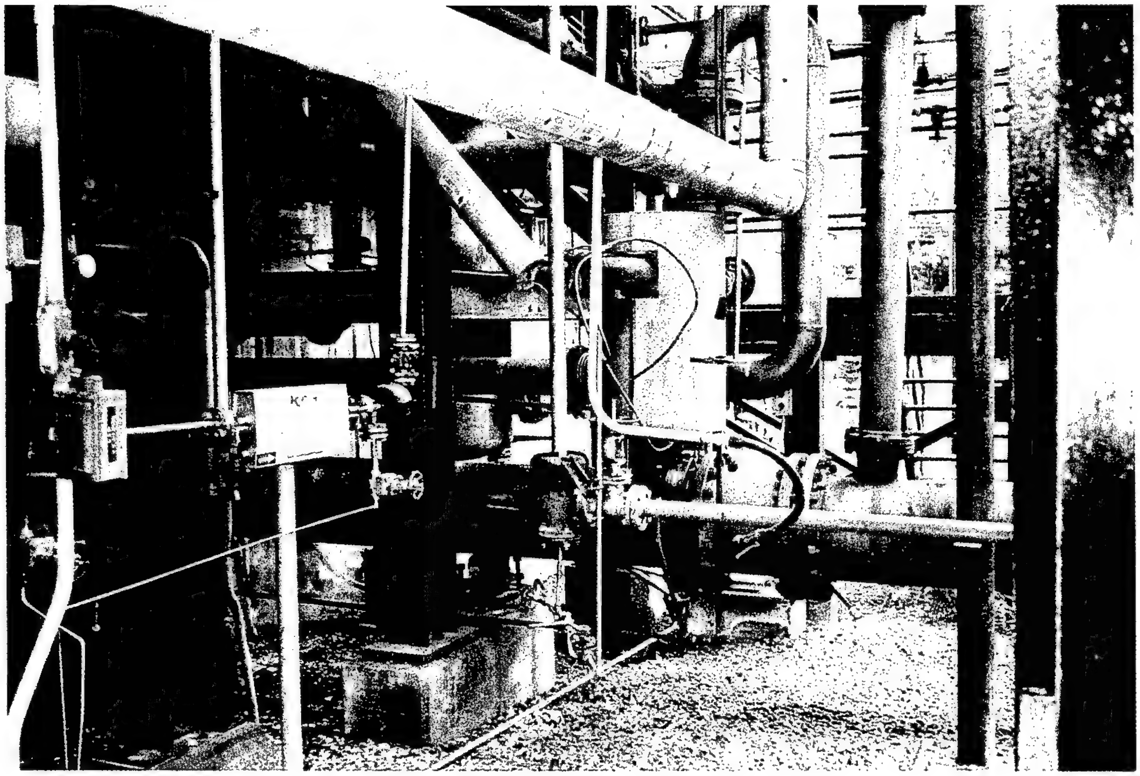
Problem Statement

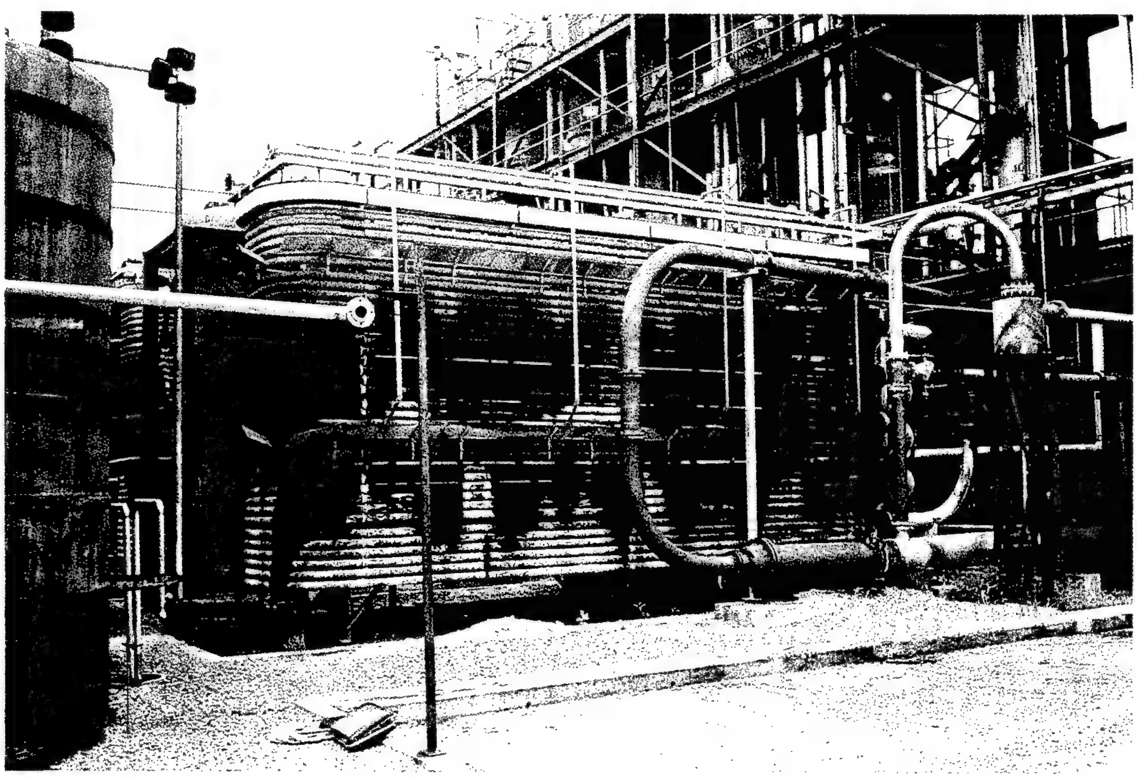
Demand by the military for explosives has declined in recent years, and continued progressively decreasing demand is forecast. Because plant mobilization to accommodate any increased military demand (i.e., renewed global conflict involving or supported by the United States) may be required on short notice, the production facilities must be maintained in a ready status.

Todays production demands are met by operating one or two of the four 50 ton/day oxidation process lines in Building 302 four continuous 24-hour days, with monthly equivalent single line operation totaling 96 hours.

Equipment providing heat rejection at the cascade cooler and the water chiller employs technology inconsistent with todays emphasis on energy efficiency. Insulation on piping and pressure vessels containing fluids at elevated temperatures is essentially non-existent. Photographs included as Figure 2 show some of these conditions. All of the steam delivered to the process equipment is discharged to drain as steam condensate. Most of the filtered river water used for process heat rejection is discharged to drain after circuiting the heat exchange equipment.

Figure 2





Purpose of the Study

The purpose of this study is to identify and evaluate the technical and economic feasibility of process or equipment modifications pursuant to conservation of energy and reduction of water consumption at the Ammonia Oxidation Process Facilities in Building 302, Area "B". An adjunct requirement is to avoid proposed modifications which would impose additional maintenance and operation requirements.

The following ECO's specifically identified by scope documents, were investigated:

1. Convert air compressor drive turbine from tailgas to steam or to steam augmentation.

2. Recover heat from product gas leaving the air preheater to produce steam.

3. Water conservation.

Additional ECO's selected by the A/E to be studied include the following:

1. Insulate heat exchangers and tailgas piping.

2. Install preformed plate heat exchangers inside insulation on air preheater and tailgas heater vessels for heat recovery to a 30 psig steam system.

3. Inject air compressor intercooler and aftercooler condensate and steam condensate from the ammonia vaporizer into tailgas entering compressor drive turbine for increased power.

Study Approach

Observations of the installation were made during field surveys conducted July 5, 1995 through July 7, 1995 and again on August 18, 1995. To further establish the A/E's understanding of the chemical processes involved, and the energy associated with the chemical reactions, two reports prepared by other consultants were reviewed. From the final report titled Limited Energy Studies by EMC Engineers, Inc. dated August 1992, a "Process Energy Inventory" tabulation for Nitric Acid Manufacturing, Building 302-B, apparently excerpted from Technical Report No. HDC-39-77 was obtained. The table is presented in the appendix under "Reference Material". The formulae for essential chemical reactions for the production of Nitric Acid by the oxidation of ammonia were obtained from Working Summary Report prepared by AAI Corporation dated December 1992.

The schematic of the AOP process included in the project Detailed Scope of Work was reconstructed to reflect existing system configuration confirmed during field surveys.

It was noted that data contained in the schematic of the AOP process from the scope documents and the previously referenced Process Energy Inventory from Technical Report No. HDC-39-77 apparently represented the system prior to installation in 1991 of four new air compressors manufactured by Joy Manufacturing Co., prior to installation in 1982 of the extended absorption columns, and prior to the installation in 1979 of the refrigerated water system (water chiller).

Process Energy Inventory

A molal analysis of the chemical reactions was performed to determine constituents of the tailgas and to establish water vapor (and liquid) quantities required to be condensed and used as diluent for the product nitric acid. From this calculation and source material from compressor and turbine manufacturers literature, an "Existing System Process Energy Inventory" was developed. The manufacturer's literature is presented in the Appendix under "Reference Material" also included in "Reference Material" are tables, formulae, charts and excerpts from various documents used in the development of the energy and chemical analysis. Table 1 shows the inventory data, which was used to prepare the Ammonia Oxidation Process Flow Diagram/Existing System presented as Figure 1 herein. All ECO's were evaluated using this data for baseline comparison.

TABLE 1. EXISTING SYSTEM PROCESS ENERGY INVENTORY

Equipment	Heat Gain		Heat Rejected			Heat Recovered			Heat Lost		Remarks
	MBH	Source	MBH	Source	Destination	MBH	Source	Recipient	MBH	Waste Stream	
Ammonia Vaporizer	714.1	Stm. Syst.	149.2	Stm. Cond.	Drain				149.2	Drain	
Mixer	178.8 (177.9)	Air NH_3									
Converter	7136.1	Reaction	2887.4	Reaction	River Water				2887.4	Drain	
Air Preheater			2902.9	Prod. Gas	Air & Atmos	2086.1	Prod. Gas	Air	816.8	Atmosph.	
Tailgas Heater			2211.4	Prod. Gas	TG & Atmos	2001.5	Prod. Gas	Tailgas	209.9	Atmosph.	
Cascade Cooler	4869.4	80% HNO_3 Reaction	2846.2	Prod. Gas & H_2O Vapor Condens.	River Water Drain & Atmos				2846.2	Drain	
Absorption Columns	1217.3	20% HNO_3 Reaction	86.5	Prod. Gas & H_2O Vapor Condens.	River Water				86.5	Drain	
Air Compressor	2018.2	Elect. Mtr	2750.6	H_2O Vapor Condens.	River Water				2750.6	Drain	793 hp
Tailgas Turbine	768.2	Heat Recovered	2097.4	Turbine Exhaust	Atmos.	768.2			1329.2	Exh to Atmosph	302 hp
Final Bleacher			118.7	Product	Product	118.7	Product	Product			
Unaccounted Losses			673.9						673.9		
TOTAL	16724.2		16724.2			4974.5			11749.7		

Assumptions

The following assumptions have been made:

1. A Molar products table based on a hydrocarbon fuel composition of $(CH_2)_n$ will yield suitable results for the products of combustion of NH_3 (ammonia), provided that the percentage of theoretical air is the same composition for the ammonia as the hydrocarbon. (Gas tables by Kennan and Kaye are sufficiently accurate).

2. Air temperature entering the mixer is automatically controlled at 625° F by mixing nominal 100° F, 115 psig air from the aftercooler with uncontrolled air leaving the air preheater.

3. Existing tailgas heater materials of high chrome iron are compatible with high temperature heat transfer fluids substituted for the tailgas.

4. Existing turbines operating on tailgas flow streams will have similar efficiency when operating on steam.

Energy Conservation Opportunities

ECO No. 1: Turbine Conversion to Steam

The existing turbines, manufactured by Dresser-Rand Steam Turbine and Motor Division, used to augment the electric motors driving the air compressors, were basically designed as steam turbines but are currently employed as gas turbines for recovery of energy contained in process tailgas. Based on energy balance documents furnished by the government, calculated shaft output with 15,450 lb/hr, 58 psig, 435°F gas at the turbine inlet is 347 hp with turbine exhaust to atmosphere. At conditions determined independently as work of this report, the calculated turbine output is 302 hp. Inlet temperatures are limited to 750°F maximum.

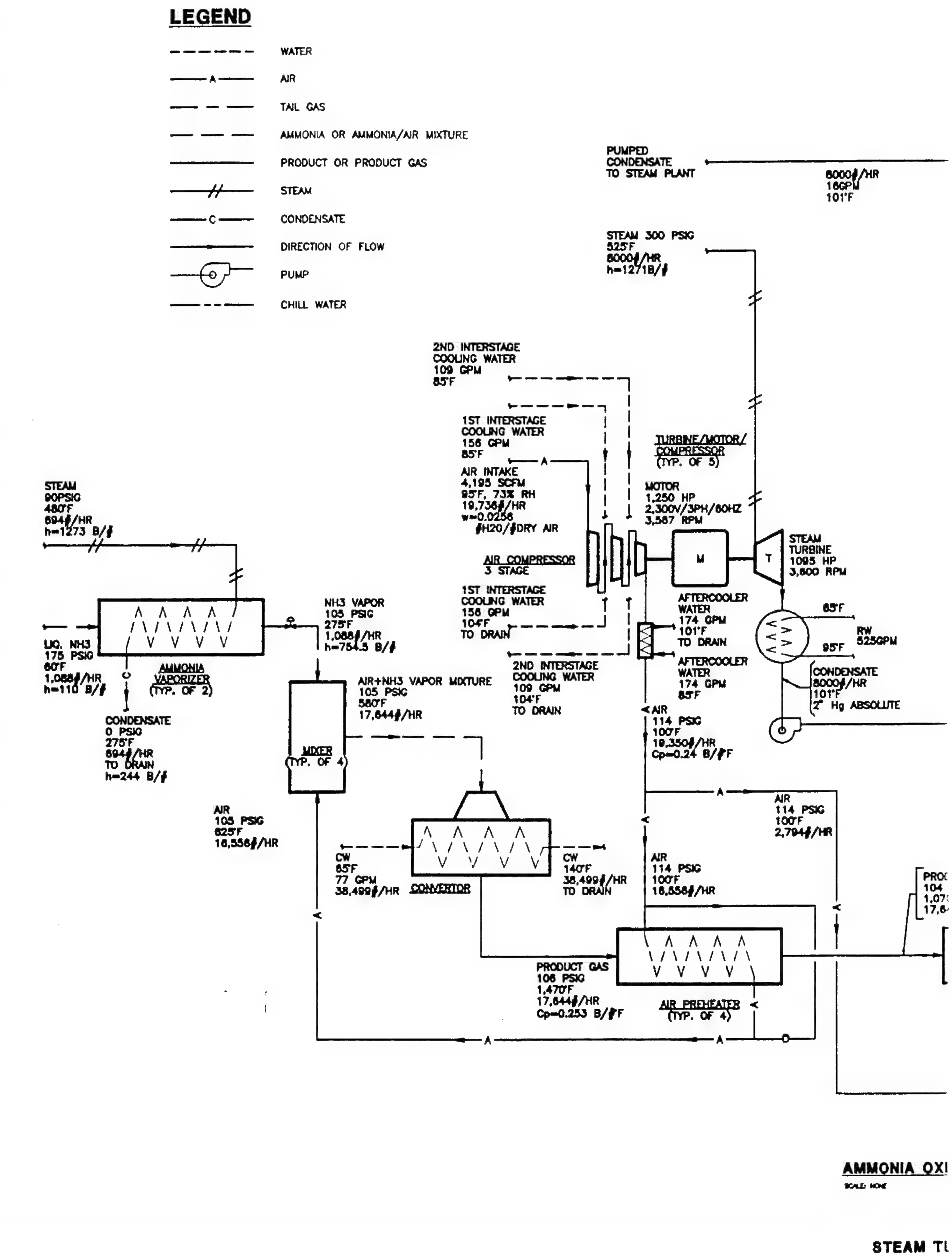
Replacement of the turbines with new 1,200 hp condensing type units to operate on the Thermodynamic Rankine Cycle with steam/water as the working fluid is proposed. Steam at 300 psig and 525°F from the central plant will be directed to the steam turbine. Turbine exhaust at 2.0 inch Hg vacuum will be condensed in a steam surface condenser using river water as the condensing medium. From the condenser, the condensate will be returned to the central plant by condenser hotwell pumps.

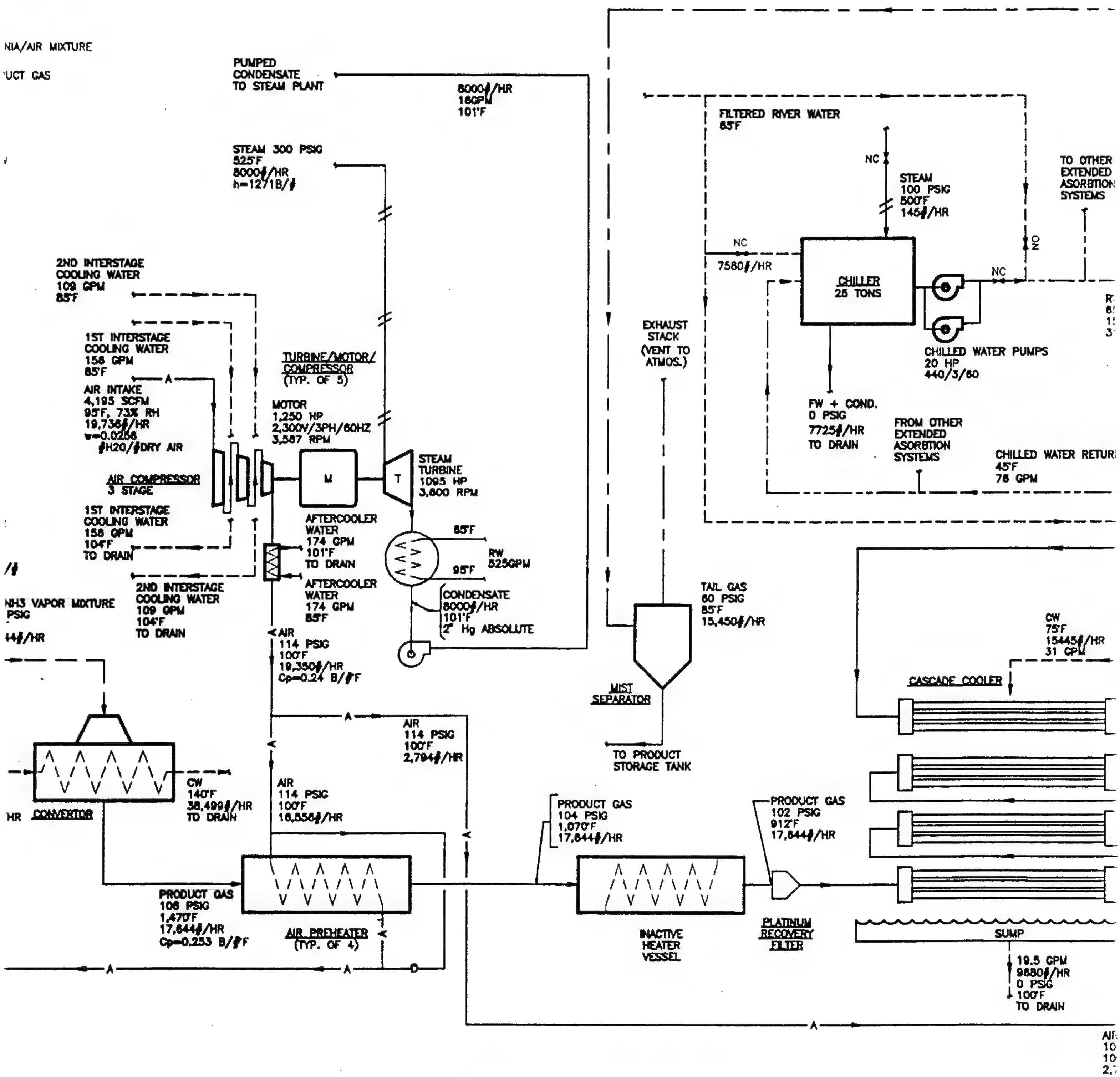
Performance of the Rankine Cycle System in the AOP process is indicated schematically in Figure 3 herein. Shaft energy produced will displace electric motor energy required to drive air compressors. Table 2 shows the energy inventory associated with ECO No. 1.

ECO No. 2: Steam Produced from Product Gas

Introduction of liquid Dowtherm A heat transfer fluid into the existing tailgas heater vessel (liquid in place of tailgas) is proposed to recover heat from the product gas prior to its introduction to the cascade heater. The fluid, the eutectic mixture of diphenyl oxide and diphenyl, would then be pumped through a closed system in which the fluid would release heat in an unfired steam boiler vessel to produce steam at 100 psig and 30°F for use in AOP process equipment or for offsetting steam production in the central plant.

Figure 3


LEGEND
WATER
AIR
TAIL GAS
AMMONIA OR AMMONIA/AIR MIXTURE
PRODUCT OR PRODUCT GAS
STEAM
CONDENSATE
DIRECTION OF FLOW
PUMP
CHILL WATER
PUMPED CONDENSATE TO STEAM PLANT
8000#/HR 16GPM 101°F
STEAM 300 PSIG 525°F 8000#/HR h=1271B/#
2ND INTERSTAGE COOLING WATER 109 GPM 85°F
1ST INTERSTAGE COOLING WATER 156 GPM 85°F
TURBINE/MOTOR/COMPRESSOR (TYP. OF 5)
AIR INTAKE 4,195 SCFM 95°F, 73% RH 19,736#/HR w=0.0256 #H20/#DRY AIR
MOTOR 1,250 HP 2,300V/3PH/60HZ 3,587 RPM
STEAM 90PSIG 480°F 694#/HR h=1273 B/#
AIR COMPRESSOR 3 STAGE
M
T
STEAM TURBINE 1095 HP 3,600 RPM
1ST INTERSTAGE COOLING WATER 156 GPM 104°F TO DRAIN
AFTERCOOLER WATER 174 GPM 101°F TO DRAIN
65°F
RW 525GPM
95°F
NH3 VAPOR 105 PSIG 275°F 1,088#/HR h=754.5 B/#
LIQ. NH3 175 PSIG 60°F 1,088#/HR h=110 B/#
AMMONIA VAPORIZER (TYP. OF 2)
AIR+NH3 VAPOR MIXTURE 105 PSIG 580°F 17,644#/HR
2ND INTERSTAGE COOLING WATER 109 GPM 104°F TO DRAIN
AFTERCOOLER WATER 174 GPM 85°F
CONDENSATE 8000#/HR 101°F 2" Hg ABSOLUTE
CONDENSATE 0 PSIG 275°F 694#/HR TO DRAIN h=244 B/#
AIR 114 PSIG 100°F 19,350#/HR Cp=0.24 B/#F
MIXER (TYP. OF 4)
AIR 114 PSIG 100°F 2,794#/HR
AIR 105 PSIG 625°F 16,556#/HR
CW 65°F 77 GPM 38,499#/HR
CONVERTOR
CW 140°F 38,499#/HR TO DRAIN
AIR 114 PSIG 100°F 16,556#/HR
PRODUCT GAS 106 PSIG 1,470°F 17,644#/HR Cp=0.253 B/#F
AIR PREHEATER (TYP. OF 4)
AMMONIA OXI
SCALE NONE
STEAM TU

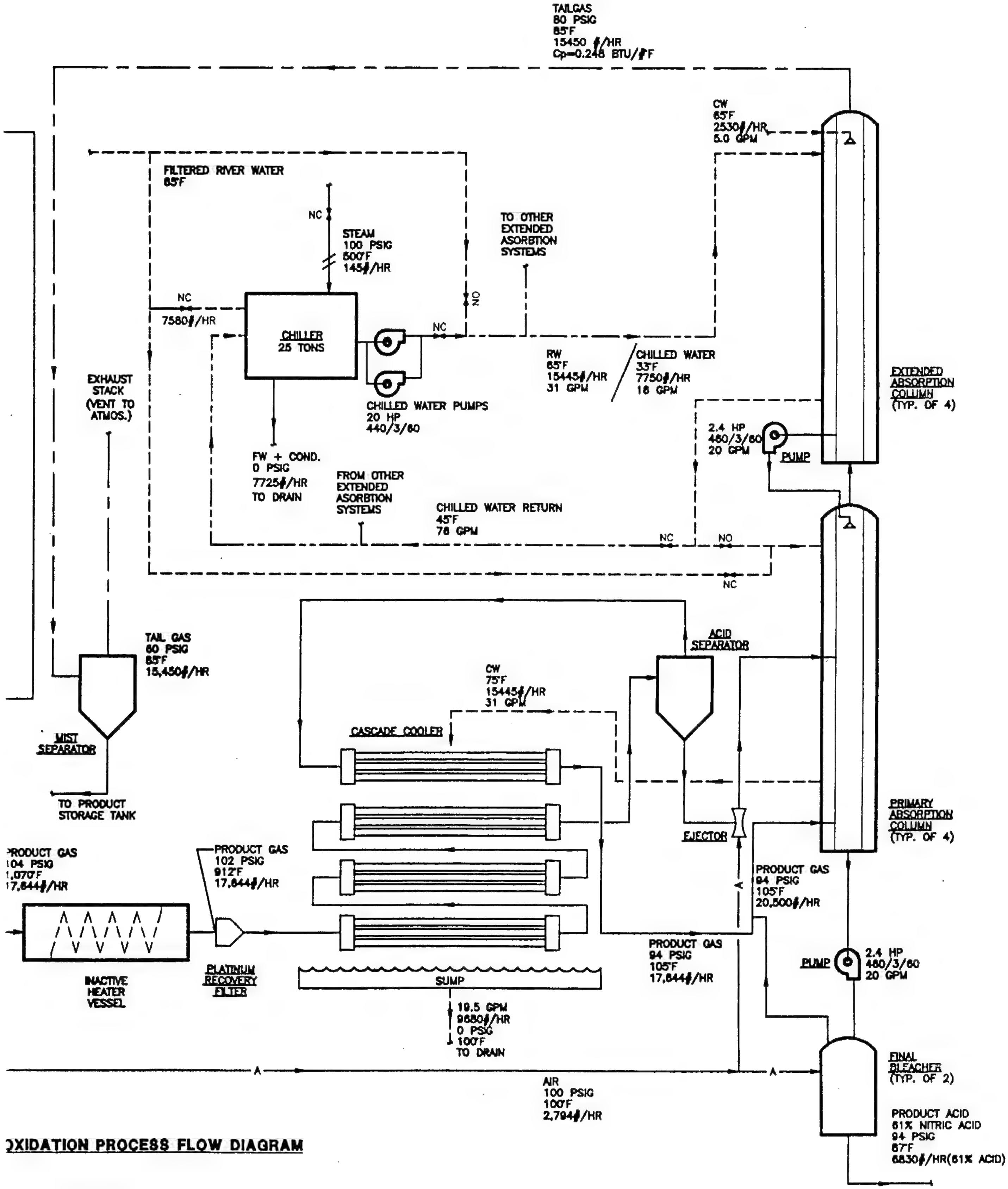


AMMONIA OXIDATION PROCESS FLOW DIAGRAM

SCALE: NONE

ECO NO. 1

STEAM TURBINE DRIVEN AIR COMPRESSOR



OXIDATION PROCESS FLOW DIAGRAM

ECO NO. 1

TURBINE DRIVEN AIR COMPRESSOR

TABLE 2. ECO NO. 1 PROCESS ENERGY INVENTORY

Equipment	Heat Gain		Heat Rejected			Heat Recovered			Heat Lost		Remarks
	MBH	Source	MBH	Source	Destination	MBH	Source	Recipient	MBH	Waste Stream	
Ammonia Vaporizer	714.1	Stm. Syst.	149.2	Stm. Cond. to Drain					149.2	Drain	
Mixer	178.8 (177.9)	Air NH_3									
Converter	7136.1	Reaction	2887.4	Reaction	River Water				2887.4	Drain	
Air Preheater			2902.9	Prod. Gas	Air & Atmos	2086.1	Prod. Gas	Air	816.8	Atmosph.	
Tailgas Heater			704.0	Prod. Gas	TG & Atmos				704.0	Atmosph.	
Cascade Cooler	4869.4	80% HNO_3 Reaction	4163.4	Prod. Gas & H_2O Vapor Condens.	River Water Drain & Atmos				4163.4	Drain	
Absorption Columns	1217.3	20% HNO_3 Reaction	86.5	Prod. Gas & H_2O Vapor Condens.	River Water				86.5	Drain	
Air Compressor	2786.8	Turbine	2750.6	H_2O Vapor Condens.	Atmos. River Water				2750.6	Atmos. Drain	
Steam Turbine	10525.0	Steam from Steam Plant	13312.0	Turbine Exhaust	Condens. & River Water	526.5	Stm. Cond.	Stm. Plnt	12785.5	Stm Surf. Cond.	12840 #/hr Steam Rqd. @ 300 psi @ 525°F - 1095 hp
Final Bleacher			118.7	Product	Product	18.7	Product	Product			
Stack Loss			95.8	Tailgas	Atmos.				95.8	Atmos.	
Unaccounted Losses			89.1						89.1		
TOTAL	27259.6		27259.6			2731.3			24528.3		

This ECO would eliminate the availability of high energy tailgas use in the existing air compressor gas turbine. Release of the low temperature tailgas to atmosphere (from 58 psig) will be a source of objectional noise. It integrates ideally into the proposed system in ECO No. 1. Table 3 shows the energy inventory associated with ECO No. 2, and Figure 4 represents the AOP process with ECO No. 2 incorporated.

ECO No. 3: Water Conservation at Chiller and Cascade Coolers

Filtered river water discharged to drain, is 20°F to 80°F above river water temperature. No contaminants are introduced into the flow streams at Building 302. It is proposed to evaporatively cool the water in an induced draft cooling tower and return it to the heat rejection equipment so that costs at the Central Water Treatment Plant can be reduced. Primarily, savings will be derived from reduced demand for aluminum sulfate and hydrated lime in the flocculation process of the filter plant.

Table 4 and Figure 5 represent the AOP process with proposed ECO No. 3 water conservation incorporated.

ECO No. 4: Insulate Heat Exchangers

Heat is released to the atmosphere by radiation and convection from the dull bare metal surface of the nominal 18 inch diameter pressure vessels and 6 inch diameter tailgas piping. Standard high temperature calcium silicate pipe insulation with protective metal jacket is to be installed to increase recovered energy used in the air compressor gas turbine drive unit. Proposed insulation thickness is 1 inch.

AOP process parameters with proposed insulation are indicated in Table 5 and in Figure 6 herein.

ECO No. 5: Insulated Heater Surfaces with Low Pressure Steam Recovery

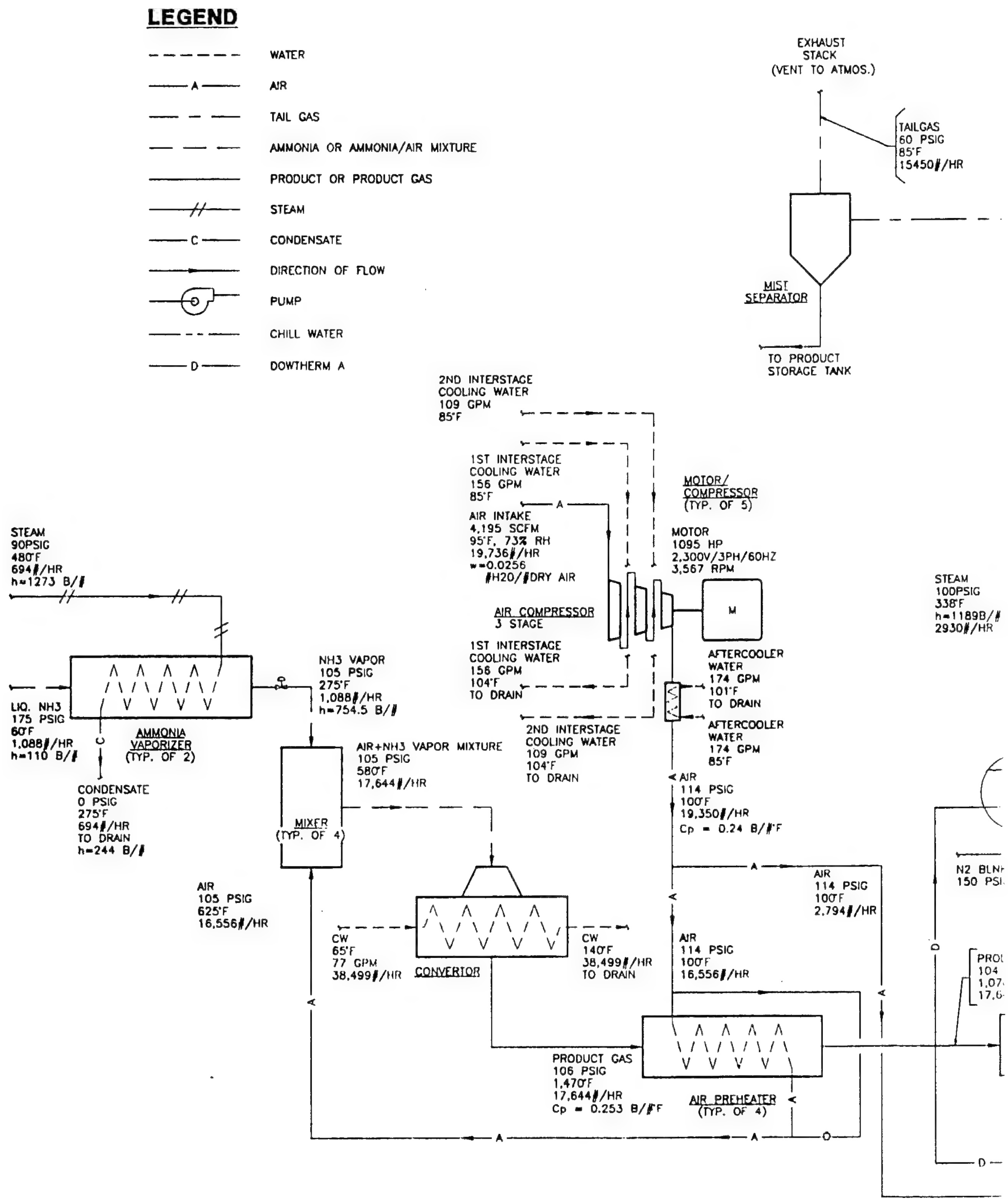
This ECO is an adjunct to ECO No. 4 - Insulate Heat Exchangers. Plant steam will still be required for production and process startup, but approximately 80% of steam used in the ammonia vaporizer will be derived from recovered energy.

A new 30 psig steam/condensate system, is proposed. The 30 psig steam is produced in a waste heat steam generator (WHSG) to extract heat from the 480°F turbine exhaust gas. Exhaust gas (tailgas) exiting the WHSG is discharged to atmosphere.

TABLE 3. ECO NO. 2 PROCESS ENERGY INVENTORY

Equipment	Heat Gain		Heat Rejected			Heat Recovered			Heat Lost		Remarks
	MBH	Source	MBH	Source	Destination	MBH	Source	Recipient	MBH	Waste Stream	
Ammonia Vaporizer	714.1	Stm. Syst.	149.2	Stm. Cond. to Drain					149.2	Drain	
Mixer	178.8 (177.9)	Air NH_3									
Converter	7136.1	Reaction	2887.4	Reaction	River Water				2887.4	Drain	
Air Preheater			2902.9	Prod. Gas	Air & Atmos	2086.1	Prod. Gas	Air	816.8	Atmosph.	
Dowtherm Heater	608.7	10% HNO_3 Reaction	3234.6	Prod. Gas	Dowtherm & Atmos.	2990.8	Prod. Gas	Dowtherm	243.8	Atmosph.	±2690 #/hr saturated steam produced @ 100 psig
Cascade Cooler	4260.5	70% HNO_3 Reaction	1949.4	Prod. Gas & H_2O Vapor Condens.	River Water Drain & Atmos				1949.4	Drain	
Absorption Columns	1217.3	20% HNO_3 Reaction	86.5	Prod. Gas & H_2O Vapor Condens.	River Water				86.5	Drain	
Air Compressor	2786.8	Elect. Meter	2750.6	H_2O Vapor Condens.	River Water				2750.6	Atmos. Drain	1095 hp
Final Bleacher			118.7	Product	Product	118.7	Product	Product			
Stack Loss			95.8	Tailgas	Atmos.				95.8	Atmos.	
Unaccounted Losses			2549.3						2549.3		
TOTAL	16724.4		16724.4			5195.6			11528.8		

Figure 4



AMMONIA OXI

SCALE: NONE

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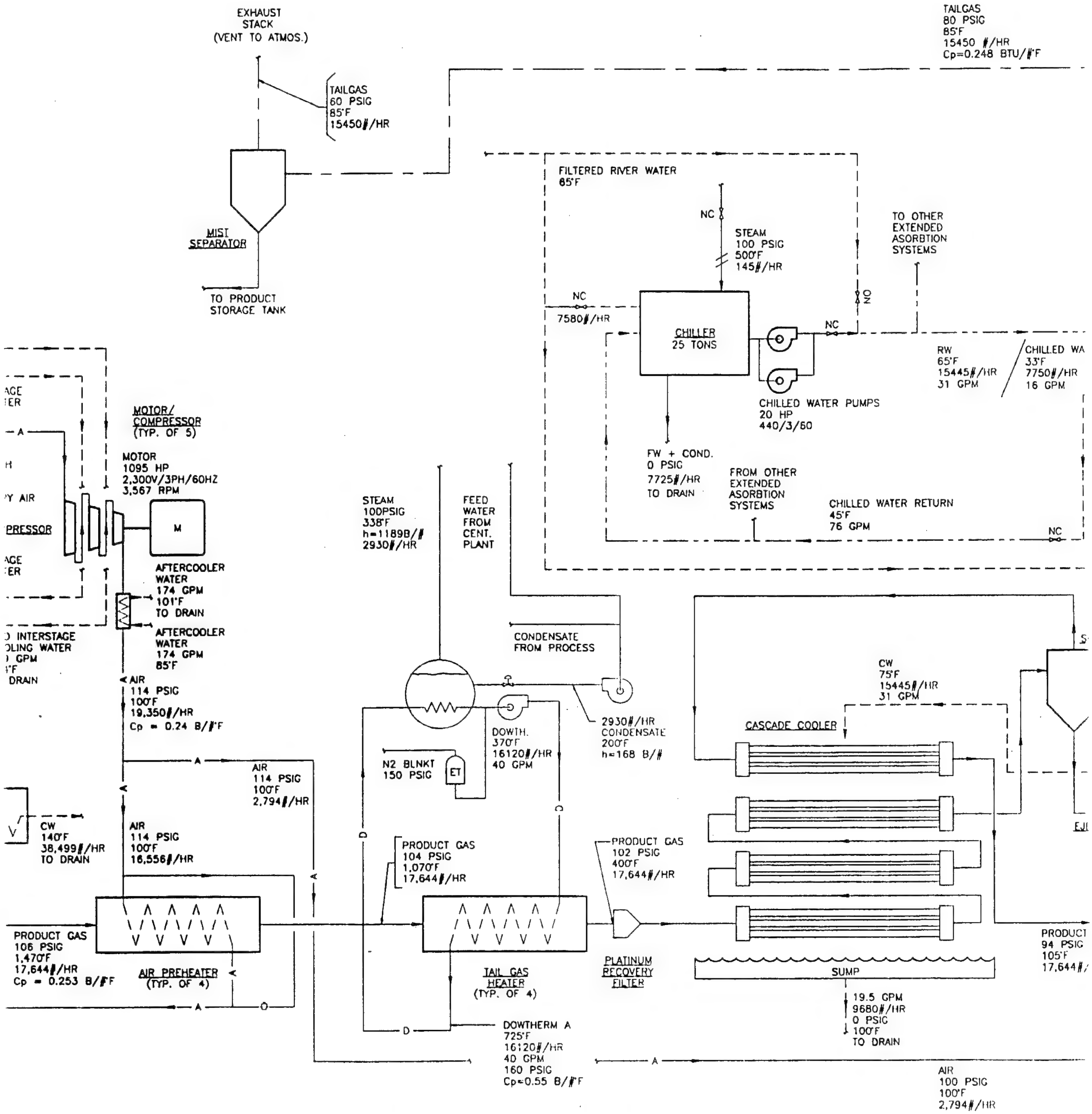


AMMONIA OXIDATION PROCESS FLOW DIAGRAM

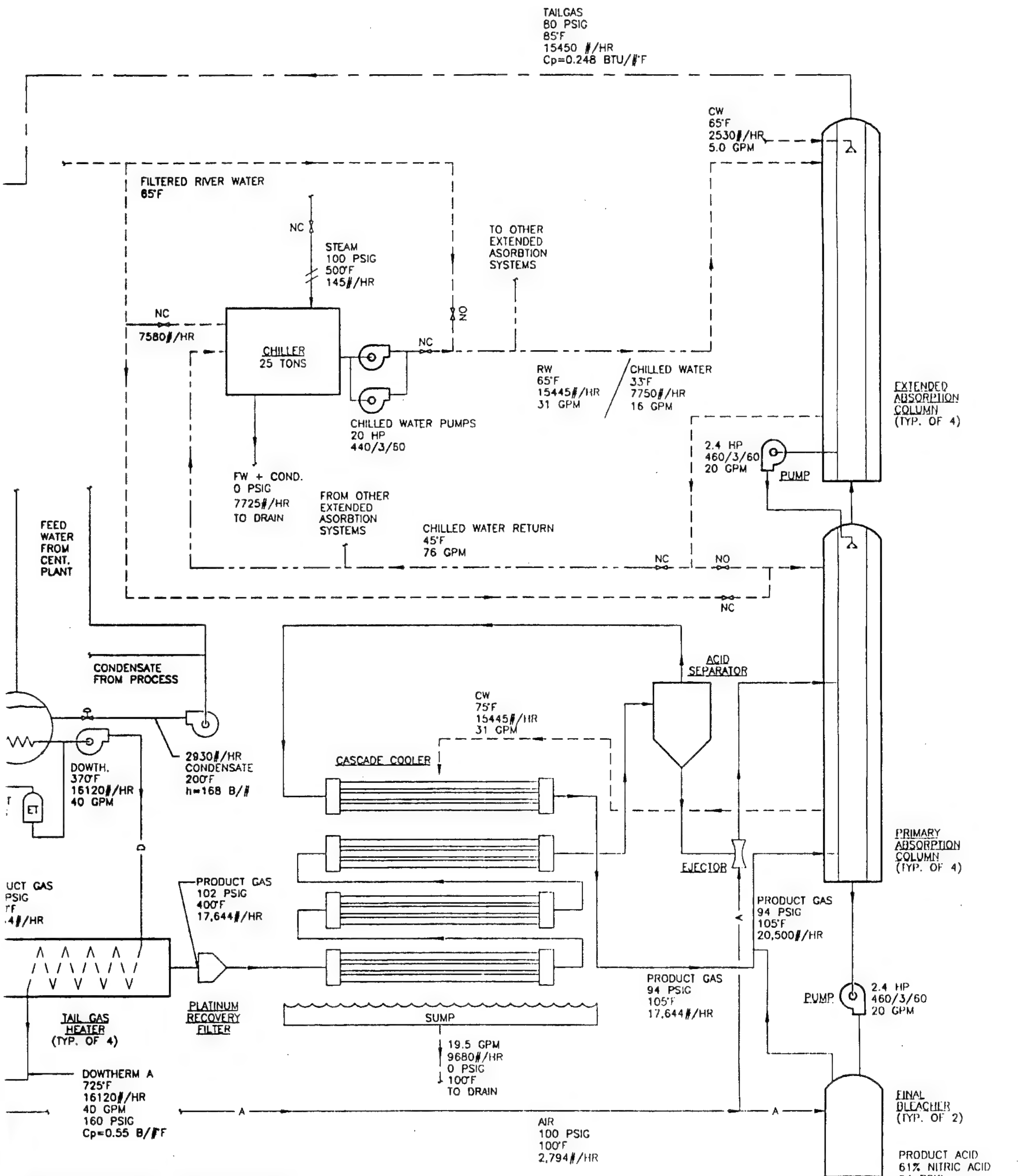
SCALE: NONE

ECO NO. 2

DOWTHERM HEAT EXCHANGER

2

HOLS



DATION PROCESS FLOW DIAGRAM

ECO NO. 2

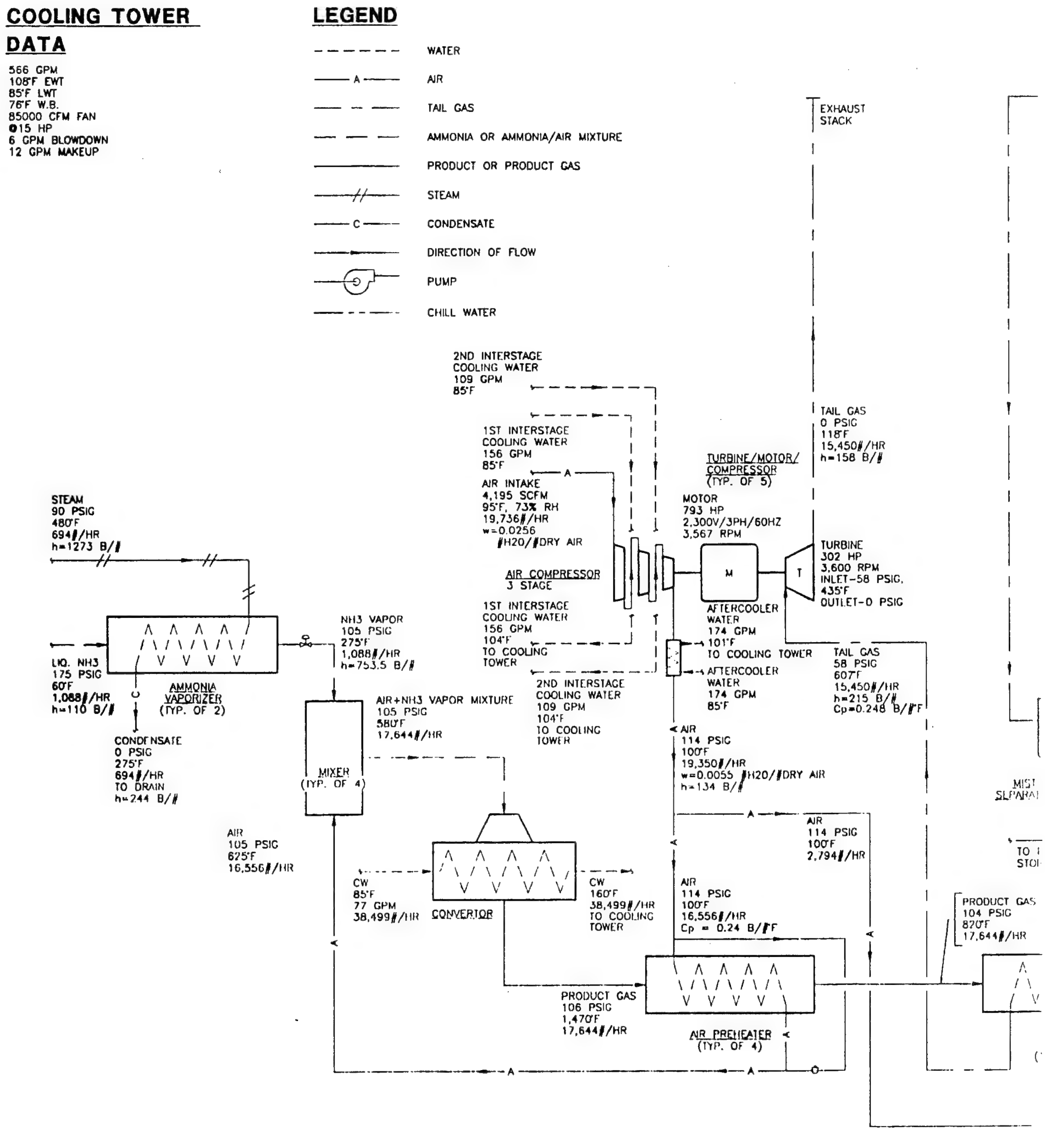
THERM HEAT EXCHANGER

3

TABLE 4. ECO NO. 3 PROCESS ENERGY INVENTORY

Equipment	Heat Gain		Heat Rejected			Heat Recovered			Heat Lost		Remarks
	MBH	Source	MBH	Source	Destination	MBH	Source	Recipient	MBH	Waste Stream	
Ammonia Vaporizer	714.1	Stm. Syst.	149.2	Stm. Cond. to Drain					149.2	Cooling Tower	
Mixer	178.8 (177.9)	Air NH_3									
Converter	7136.1	Reaction	2887.4	Reaction	River Water				2887.4	Cooling Tower	
Air Preheater			2902.9	Prod. Gas	Air & Atmos	2086.1	Prod. Gas	Air	816.8	Atmosph.	
Tailgas Heater			2211.4	Prod. Gas	TG & Atmos	2001.5	Prod. Gas	Tailgas	209.9	Atmosph.	
Cascade Cooler	4869.4	80% HNO_3 Reaction	2846.2	Prod. Gas & H_2O Vapor Condens.	River Water Drain & Atmos				2846.2	Cooling Tower	
Absorption Columns	1217.3	20% HNO_3 Reaction	86.5	Prod. Gas & H_2O Vapor Condens.	River Water				86.5	Cooling Tower	
Air Compressor	2018.2	Elect. Meter	2750.6	H_2O Vapor Condens.	River Water				2750.6	Cooling Tower	793 hp
Tailgas Turbine	768.2		2097.4			768.2			1329.2	Exh. to Atmosph	302 hp
Final Bleacher			118.7	Product	Product	118.7	Product	Product			
Unaccounted Losses			673.9						673.9		
TOTAL	16724.2		16724.2			4974.5			11749.7		

Figure 5



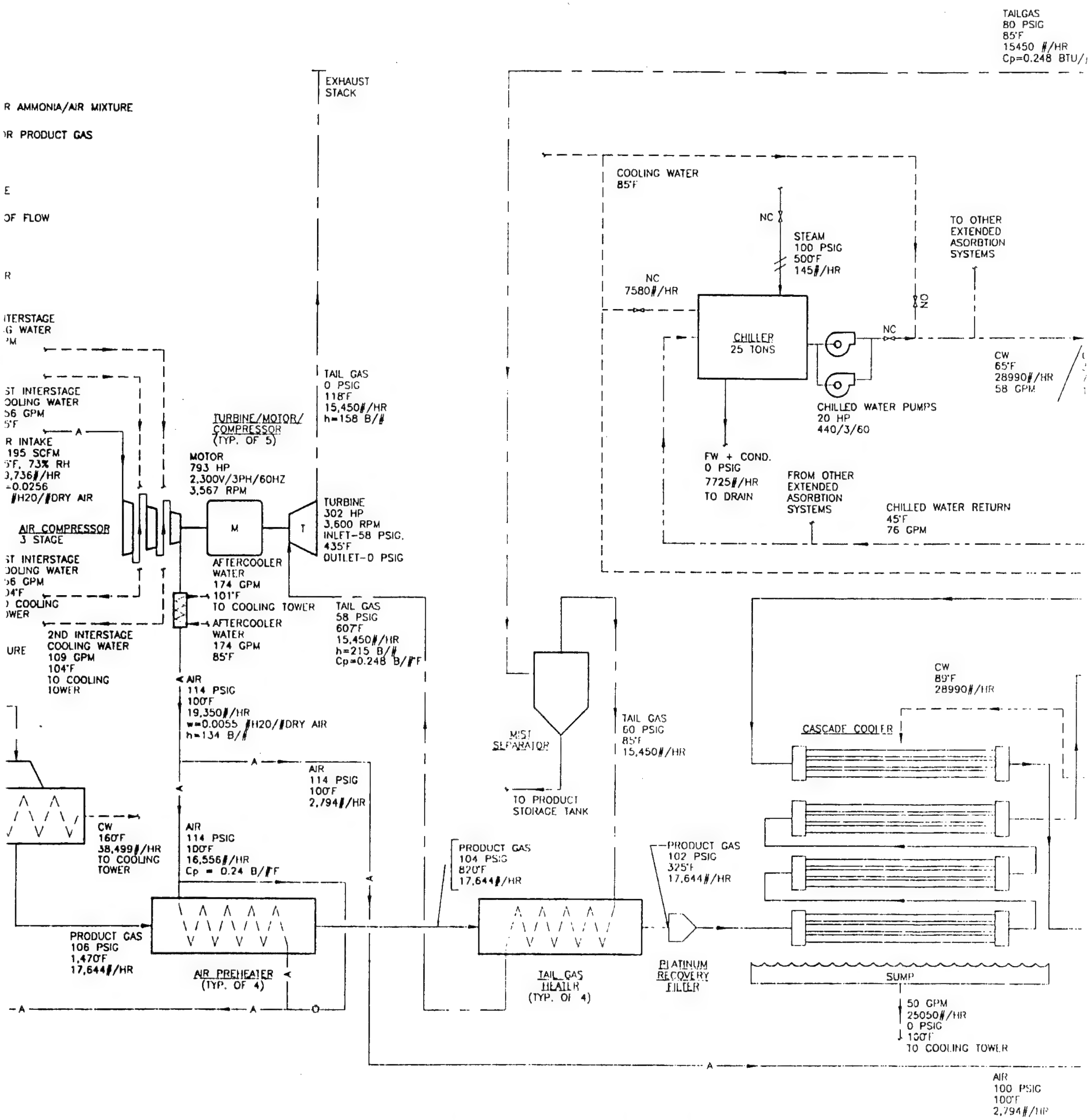
AMMONIA OXIDATIO

SCALE: NONE

EC

INCORPORA

1



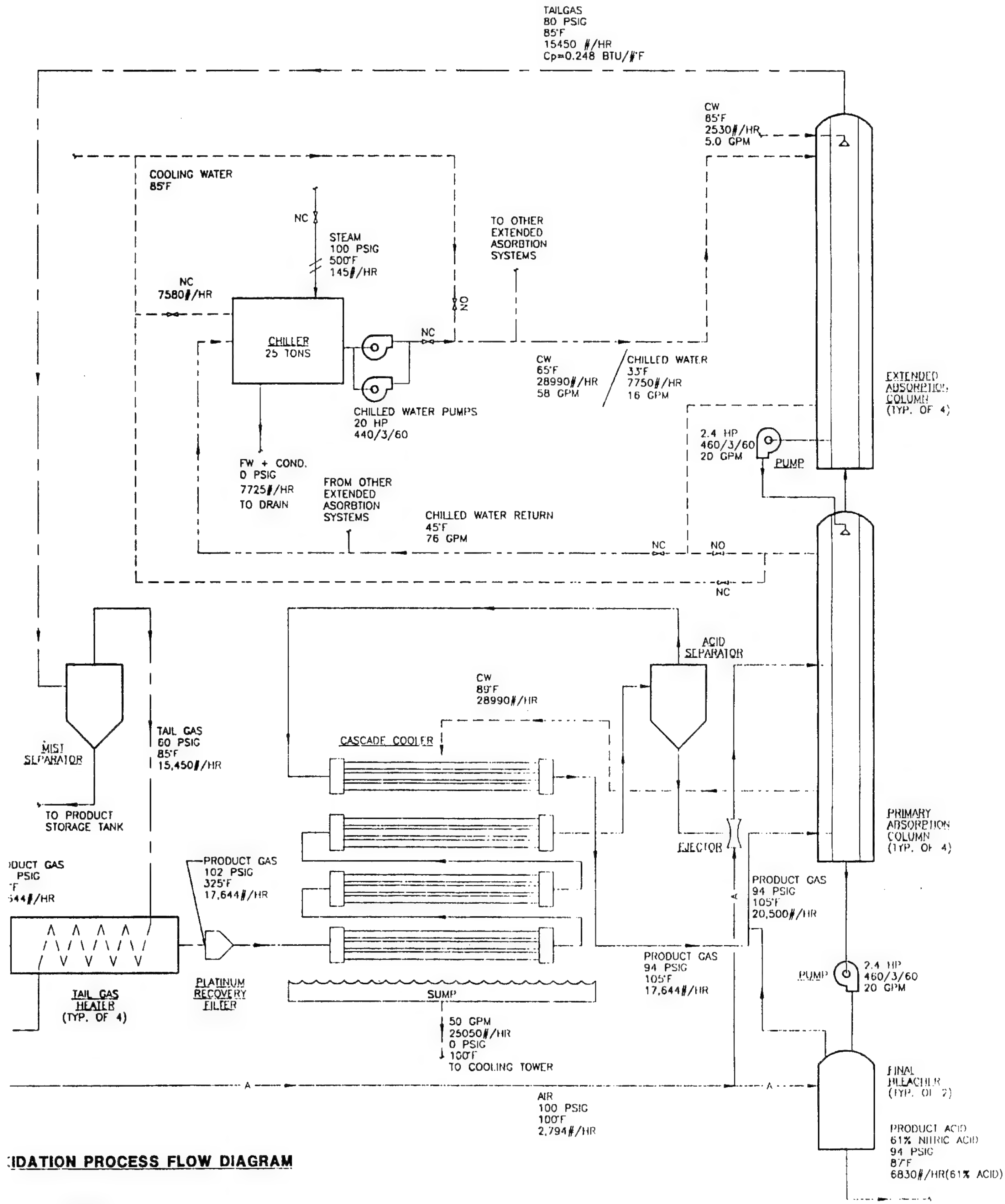
AMMONIA OXIDATION PROCESS FLOW DIAGRAM

SCALE: NONE

ECO NO. 3

INCORPORATE COOLING TOWER

2



IDATION PROCESS FLOW DIAGRAM

ECO NO. 3

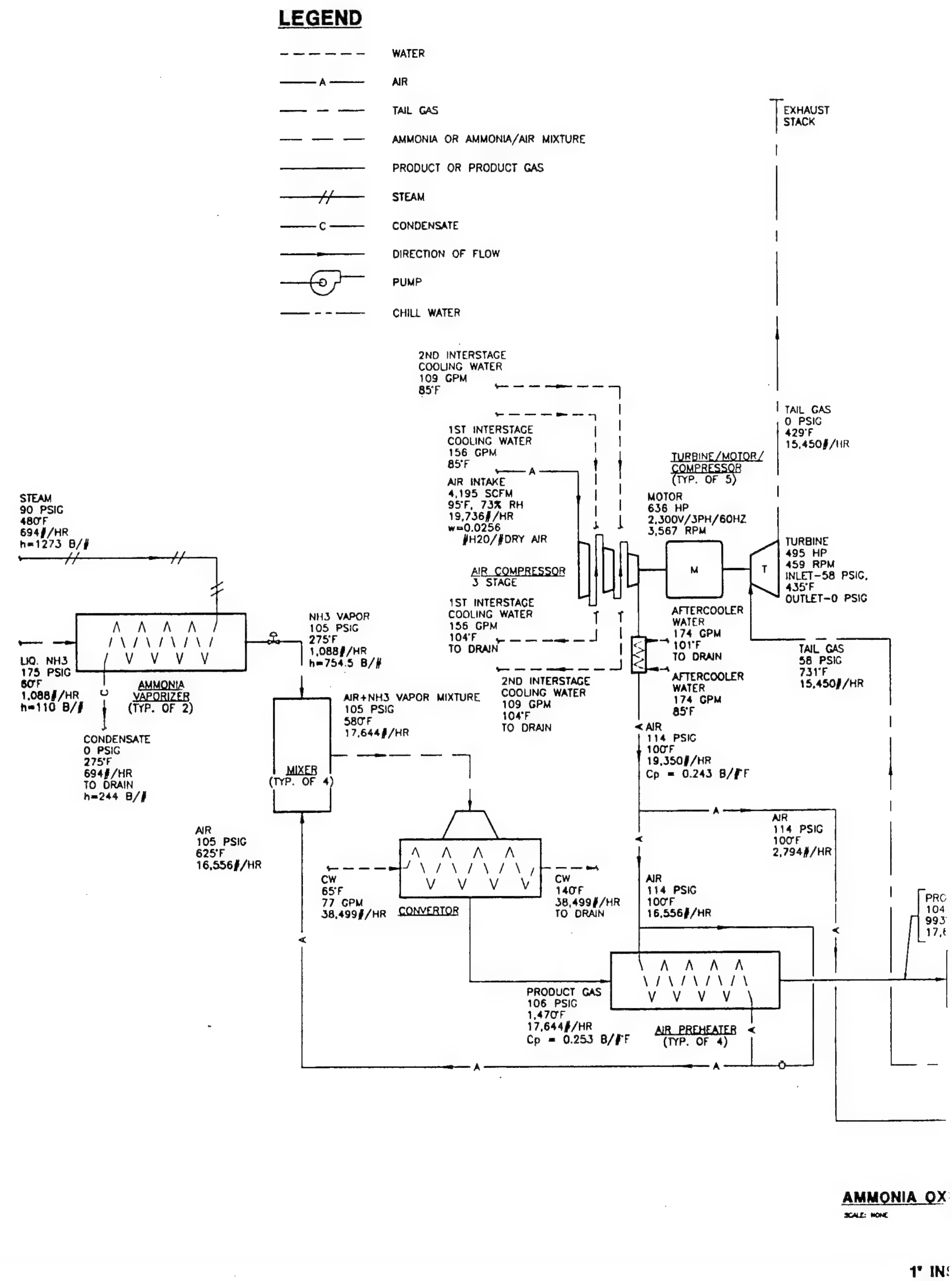
RPORATE COOLING TOWER

3

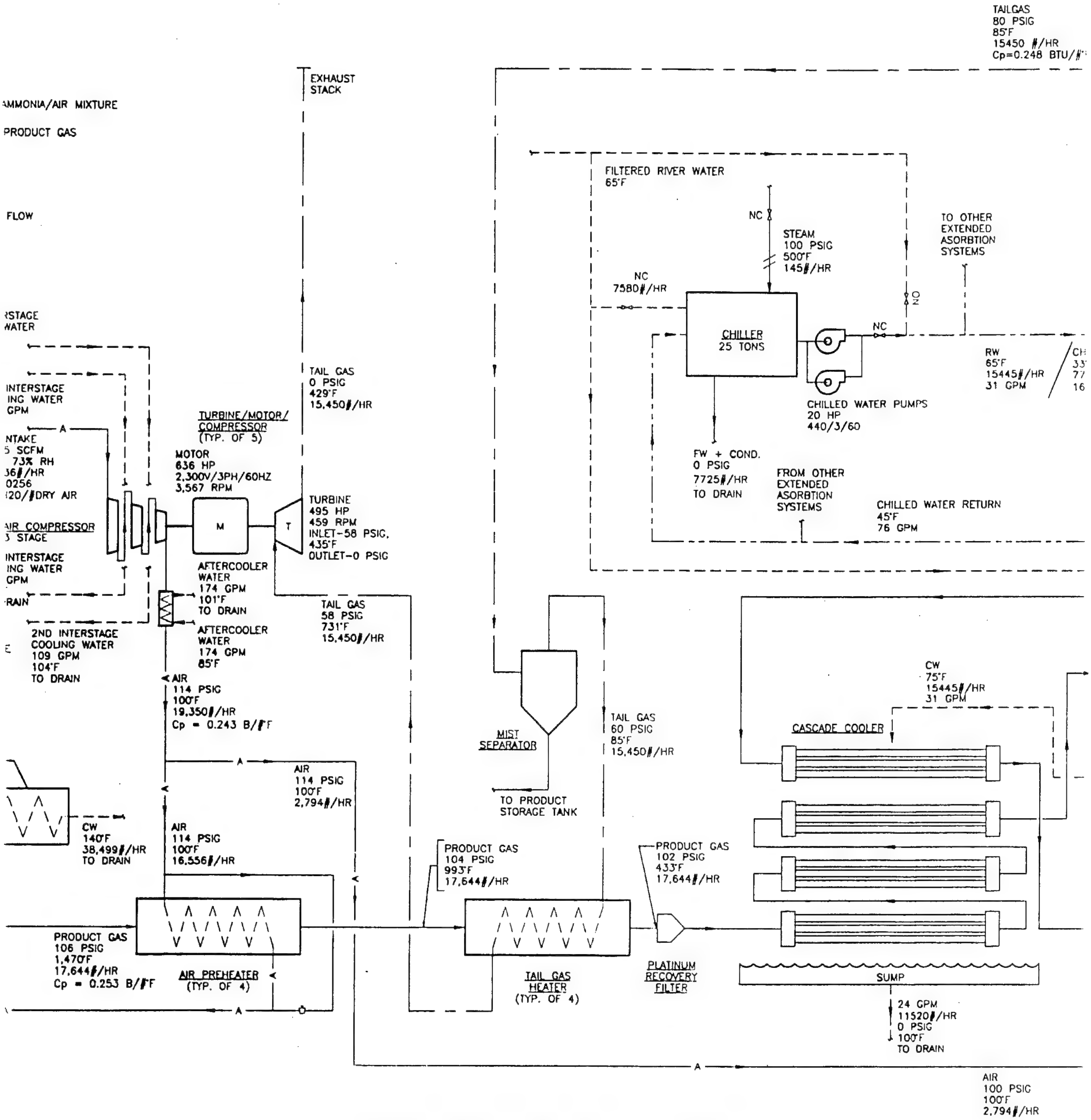
TABLE 5. ECO NO. 4 PROCESS ENERGY INVENTORY

Equipment	Heat Gain		Heat Rejected			Heat Recovered			Heat Lost		Remarks
	MBH	Source	MBH	Source	Destination	MBH	Source	Recipient	MBH	Waste Stream	
Ammonia Vaporizer	714.1	Stm. Syst.	149.2	Stm. Cond. to Drain					149.2	Drain	
Mixer	178.8 (177.9)	Air NH_3									
Converter	7136.1	Reaction	2887.4	Reaction	River Water				2887.4	Drain	
Air Preheater			2128.8	Prod. Gas	Air & Atmos	2086.1	Prod. Gas	Air	42.7	Atmosph.	
Tailgas Heater			2496.7	Prod. Gas	TG & Atmos	2473.6	Prod. Gas	Tailgas	23.1	Atmosph.	
Cascade Cooler	4869.4	80% HNO_3 Reaction	2092.1	Prod. Gas & H_2O Vapor Condens.	River Water Drain & Atmos				2092.1	Drain	
Absorption Columns	1217.3	20% HNO_3 Reaction	86.5	Prod. Gas & H_2O Vapor Condens.	River Water				86.5	Drain	
Air Compressor	1618.6	Elect. Meter	2750.6	H_2O Vapor Condens.	River Water				2750.6	Drain	636 hp
Tailgas Turbine	1168.2	Recovered Heater	2582.1	Tailgas	Atmos.	1168.2			1413.9	Exh. to Atmosph	459 hp
Final Bleacher			118.7	Product	Product	118.7	Product	Product			
Unaccounted Losses			1432.5						1432.5		
TOTAL	16724.6		16724.6			5846.6			10878.0		

Figure 6



LEGEND
WATER
AIR
TAIL GAS
AMMONIA OR AMMONIA/AIR MIXTURE
PRODUCT OR PRODUCT GAS
STEAM
CONDENSATE
DIRECTION OF FLOW
PUMP
CHILL WATER
EXHAUST STACK
2ND INTERSTAGE COOLING WATER 109 GPM 85°F
1ST INTERSTAGE COOLING WATER 156 GPM 85°F
AIR INTAKE 4,195 SCFM 95°F, 73% RH 19,736#/HR w=0.0256 #H20/#DRY AIR
TAIL GAS 0 PSIG 429°F 15,450#/HR
TURBINE/MOTOR/ COMPRESSOR (TYP. OF 5)
MOTOR 636 HP 2,300V/3PH/60HZ 3,567 RPM
STEAM 90 PSIG 480°F 694#/HR h=1273 B/#
AIR COMPRESSOR 3 STAGE
TURBINE 495 HP 459 RPM INLET-58 PSIG, 435°F OUTLET-0 PSIG
1ST INTERSTAGE COOLING WATER 156 GPM 104°F TO DRAIN
AFTERCOOLER WATER 174 GPM 101°F TO DRAIN
NH3 VAPOR 105 PSIG 275°F 1,088#/HR h=754.5 B/#
TAIL GAS 58 PSIG 731°F 15,450#/HR
LIQ. NH3 175 PSIG 60°F 1,088#/HR h=110 B/#
AMMONIA VAPORIZER (TYP. OF 2)
2ND INTERSTAGE COOLING WATER 109 GPM 104°F TO DRAIN
AFTERCOOLER WATER 174 GPM 85°F
AIR+NH3 VAPOR MIXTURE 105 PSIG 580°F 17,644#/HR
AIR 114 PSIG 100°F 19,350#/HR Cp = 0.243 B/#°F
CONDENSATE 0 PSIG 275°F 694#/HR TO DRAIN h=244 B/#
MIXER (TYP. OF 4)
AIR 114 PSIG 100°F 2,794#/HR
AIR 105 PSIG 625°F 16,556#/HR
CW 65°F 77 GPM 38,499#/HR
CONVERTOR
CW 140°F 38,499#/HR TO DRAIN
AIR 114 PSIG 100°F 16,556#/HR
PRODUCT GAS 106 PSIG 1,470°F 17,644#/HR Cp = 0.253 B/#°F
AIR PREHEATER (TYP. OF 4)
AMMONIA OX
SCALE: NONE
1" IN

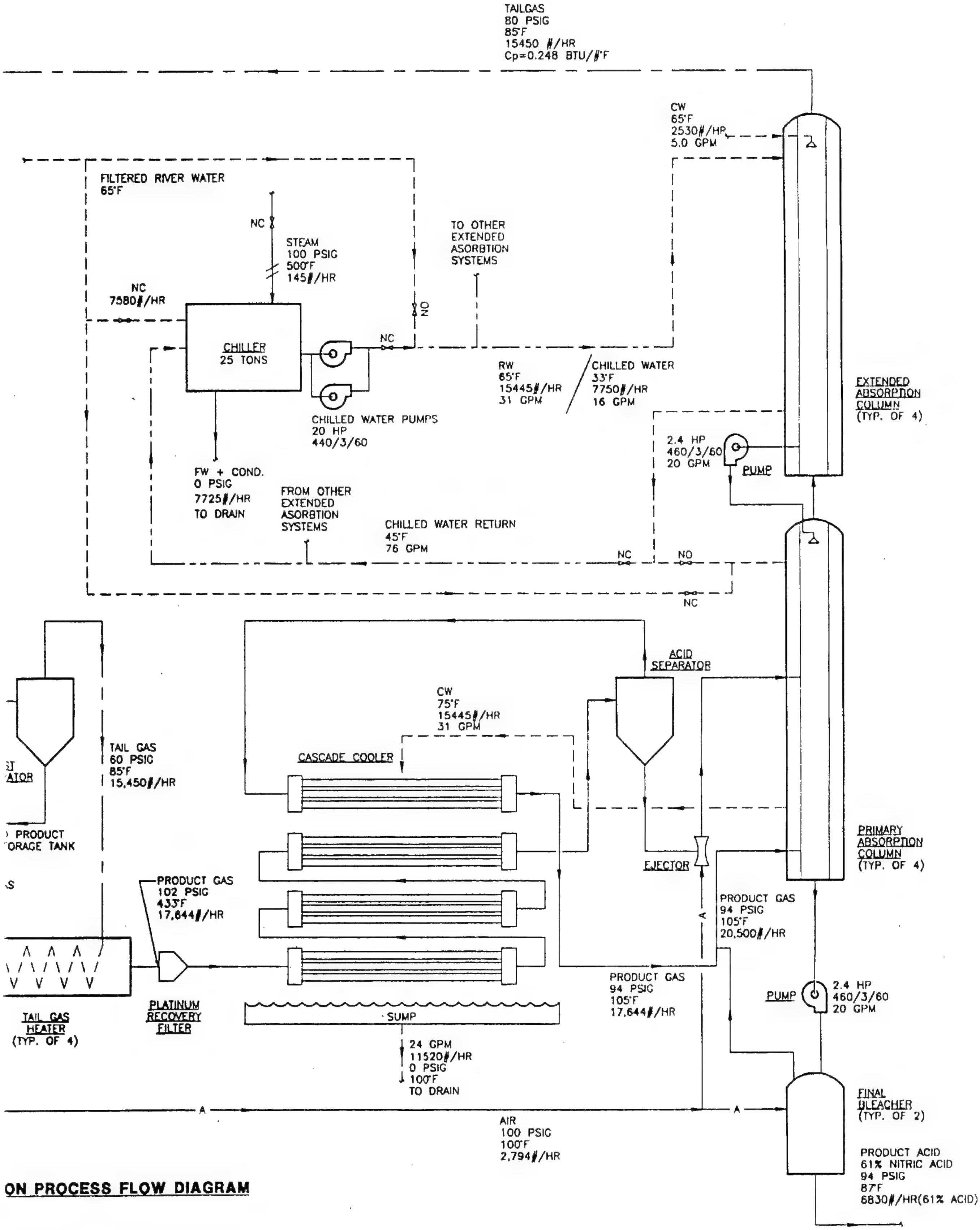


AMMONIA OXIDATION PROCESS FLOW DIAGRAM

SCALE: NONE

ECO NO.4

1" INSULATION ON HEATERS



ON PROCESS FLOW DIAGRAM

CO NO.4

TION ON HEATERS

Results of integrating this ECO into the AOP process are shown in Table 6 and Figure 7.

ECO No. 6: Water Injection at Gas Turbine

Not developed.

ECO No. 7: Recovered Steam Injected at Tailgas Turbine Inlet

Recovery of relatively pure water obtained from air compressor intercoolers and aftercoolers and from steam trap discharge at the ammonia vaporizer, all of which is presently discharged to waste, will be utilized for makeup to a waste heat steam generating system (WHSG) consisting of two recovery sections, one located in product gas stream leaving the platinum filter and the other in the wet gas stream leaving the turbine, and a steam separator vessel.

Additional boiler water makeup (approximately 10%) from the steam plant will augment the recovered water. Steam from the WHSG will be introduced into the hot tailgas from the tailgas heater to increase turbine output and offset electrical load of the compressor drive motor, and will be discharged to atmosphere along with the tailgas.

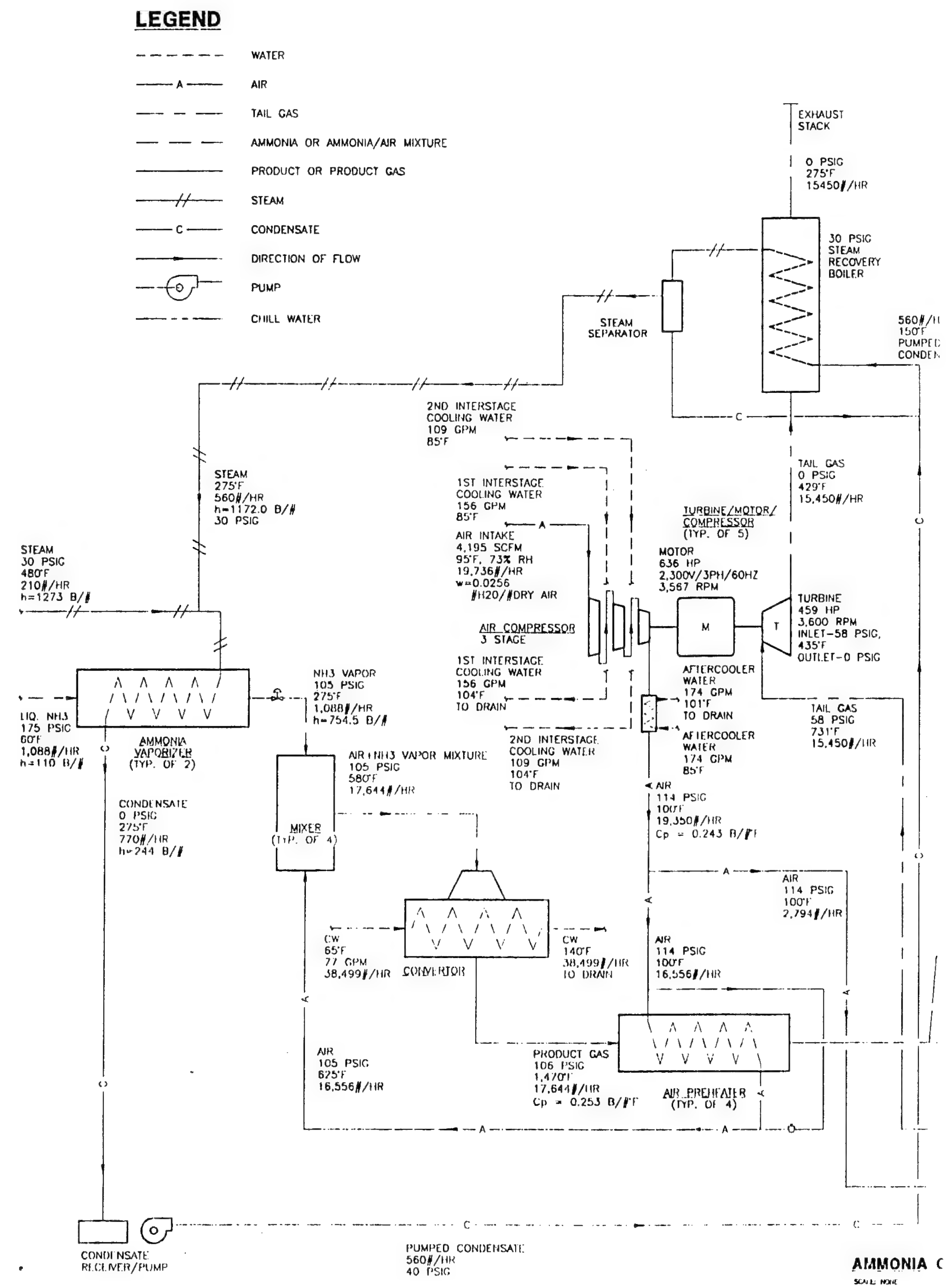
Introduction of the steam into the tailgas will be made at a sufficient distance upstream of the turbine inlet, in the existing 6 inch diameter standard black iron piping. The WHSG section in the product gas stream will be constructed of high chromium stainless steel (400 series) for surfaces in contact with product gas. The wet gas WHSG section will be standard steel construction as offered by Clayton Industries, El Monte, CA.

AOP process parameters with the proposed steam injection system, incorporated with the insulation evaluated in ECO #4, are shown in Table 7 and Figure 8 herein.

TABLE 6. ECO NO. 5 PROCESS ENERGY INVENTORY

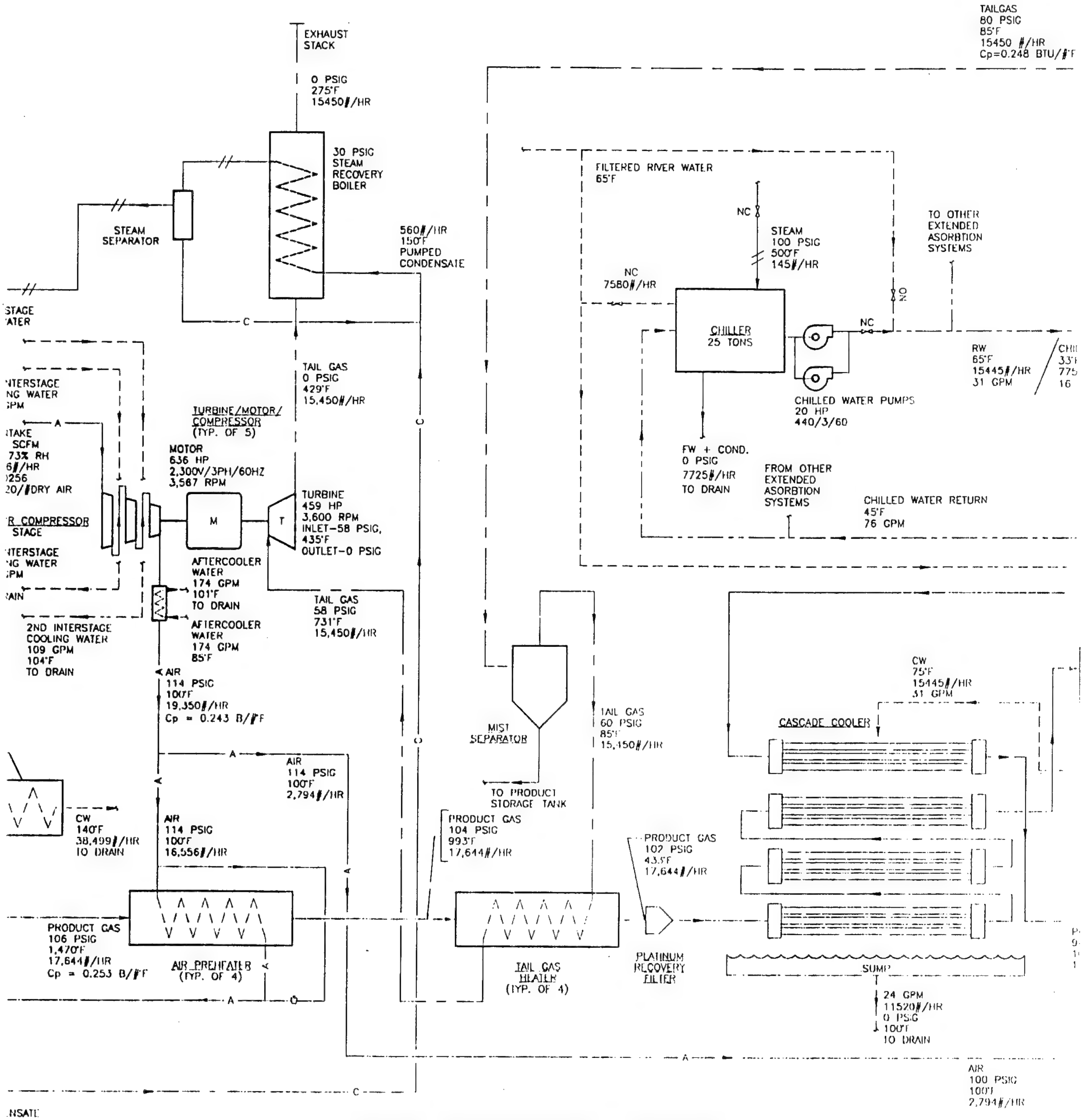
Equipment	Heat Gain		Heat Rejected			Heat Recovered			Heat Lost		Remarks
	MBH	Source	MBH	Source	Destination	MBH	Source	Recipient	MBH	Waste Stream	
Ammonia Vaporizer	714.1	L.P. Steam	149.2	Steam Cond.	Drain	149.2	Steam Cond.	LP Steam			
Mixer	178.8 (177.9)	Air NH_3									
Converter	7136.1	Reaction	2887.4	Reaction	River Water				2887.4	Drain	
Air Preheater			2128.8	Prod. Gas	Air & Atmos	2086.1	Prod. Gas	Air	42.7	Atmosph.	
Tailgas Heater			2496.7	Prod. Gas	TG & Atmos & L.P. Stm	2473.6	Prod. Gas Prod. Gas	Tailgas L.P. Stm Syst.	23.1	Atmosph.	
Cascade Cooler	4869.4	80% HNO_3 Reaction	2092.1	Prod. Gas & H_2O Vapor Condens.	River Water Drain & Atmos				2092.1	Drain	
Absorption Columns	1217.3	20% HNO_3 Reaction	86.5	Prod. Gas & H_2O Vapor Condens.	River Water				86.5	Drain	
Air Compressor	1618.6	Elect. Meter	2750.6	H_2O Vapor Condens.	River Water				2750.6	Drain	636 hp
Tailgas Turbine	1168.2	Recovered Heat	2582.1	Turb. Exh.	Stack	1758.3	Stack	L.P. Stm Syst.	823.8	Exh. to Atmosph	459 hp
Final Bleacher			118.7	Product	Product	118.7	Product	Product			
Unaccounted Losses			1432.5						1432.5		
TOTAL	16724.6		16724.6			6585.9			10138.7		

Figure 7



LEGEND
WATER
AIR
TAIL GAS
AMMONIA OR AMMONIA/AIR MIXTURE
PRODUCT OR PRODUCT GAS
STEAM
CONDENSATE
DIRECTION OF FLOW
PUMP
CHILL WATER
EXHAUST STACK
0 PSIG 275°F 15450#/HR
30 PSIG STEAM RECOVERY BOILER
STEAM SEPARATOR
560#/HR 150°F PUMPED CONDEN
2ND INTERSTAGE COOLING WATER 109 GPM 85°F
1ST INTERSTAGE COOLING WATER 156 GPM 85°F
TAIL GAS 0 PSIG 429°F 15,450#/HR
TURBINE/MOTOR/ COMPRESSOR (TYP. OF 5)
STEAM 275°F 560#/HR h=1172.0 B/# 30 PSIG
AIR INTAKE 4,195 SCFM 95°F, 73% RH 19,736#/HR w=0.0256 #H20/#DRY AIR
MOTOR 636 HP 2,300V/3PH/60HZ 3,567 RPM
STEAM 30 PSIG 480°F 210#/HR h=1273 B/#
TURBINE 459 HP 3,600 RPM INLET-58 PSIG, 435°F OUTLET-0 PSIG
AIR COMPRESSOR 3 STAGE
1ST INTERSTAGE COOLING WATER 156 GPM 104°F TO DRAIN
AFTERCOOLER WATER 174 GPM 101°F TO DRAIN
NH3 VAPOR 105 PSIG 275°F 1,088#/HR h=754.5 B/#
TAIL GAS 58 PSIG 731°F 15,450#/HR
LIQ. NH3 175 PSIG 60°F 1,088#/HR h=110 B/#
AMMONIA VAPORIZER (TYP. OF 2)
AIR+NH3 VAPOR MIXTURE 105 PSIG 580°F 17,644#/HR
2ND INTERSTAGE COOLING WATER 109 GPM 104°F TO DRAIN
AFTERCOOLER WATER 174 GPM 85°F
AIR 114 PSIG 100°F 19,350#/HR Cp = 0.243 B/#°F
CONDENSATE 0 PSIG 275°F 770#/HR h=244 B/#
MIXER (TYP. OF 4)
AIR 114 PSIG 100°F 2,794#/HR
CW 65°F 77 GPM 38,499#/HR
CONVERTOR
CW 140°F 38,499#/HR TO DRAIN
AIR 114 PSIG 100°F 16,556#/HR
AIR 105 PSIG 625°F 16,556#/HR
PRODUCT GAS 106 PSIG 1,470°F 17,644#/HR Cp = 0.253 B/#°F
AIR PREHEATER (TYP. OF 4)
CONDENSATE RECEIVER/PUMP
PUMPED CONDENSATE 560#/HR 40 PSIG
AMMONIA C
SCALE: NONE
WITH LOW

①



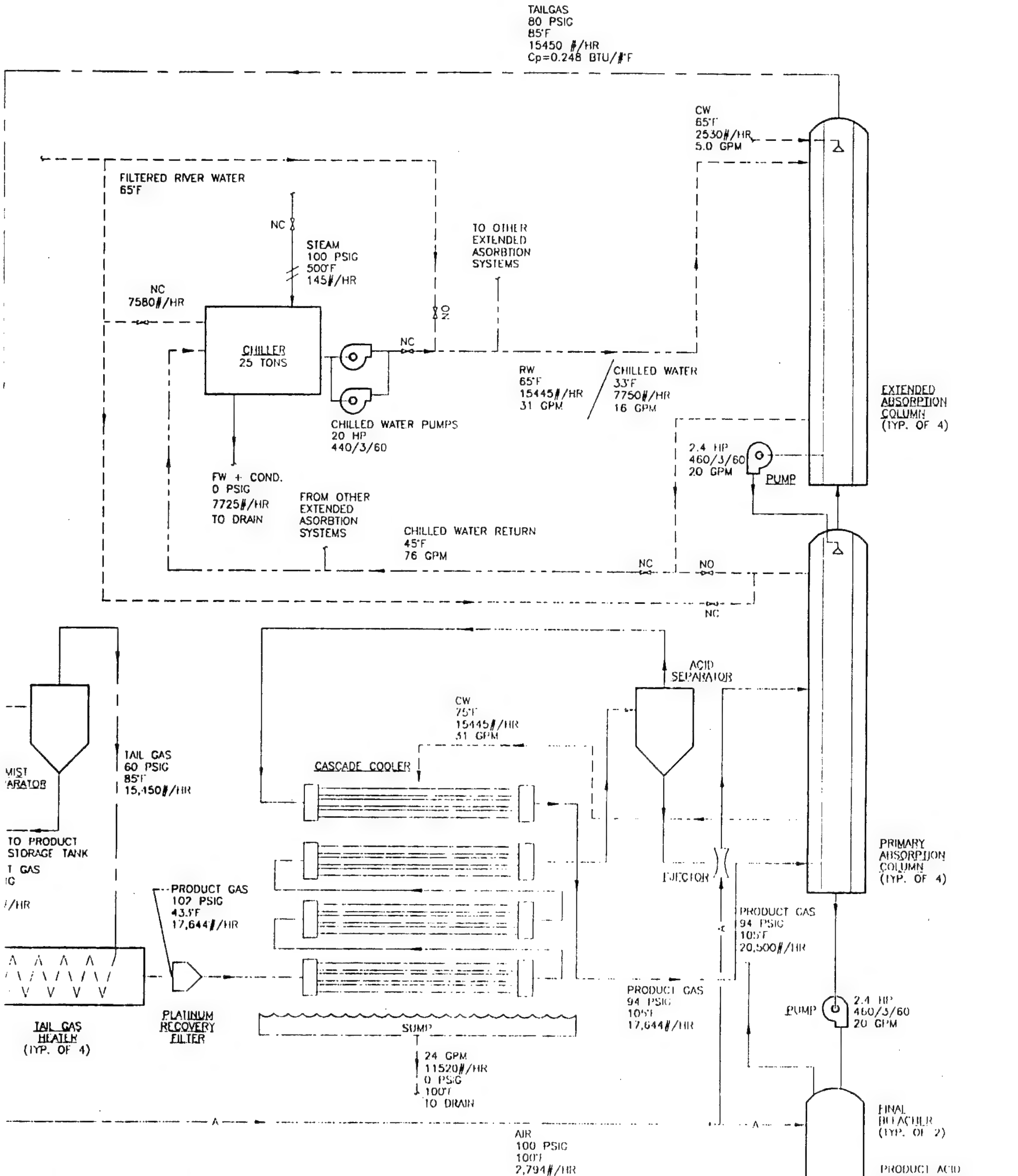
AMMONIA OXIDATION PROCESS FLOW DIAGRAM

SCALE: NONE

ECO NO.5

1" INSULATION ON HEATERS WITH LOW PRESSURE STEAM RECOVERY

2



ION PROCESS FLOW DIAGRAM

ECO NO.5

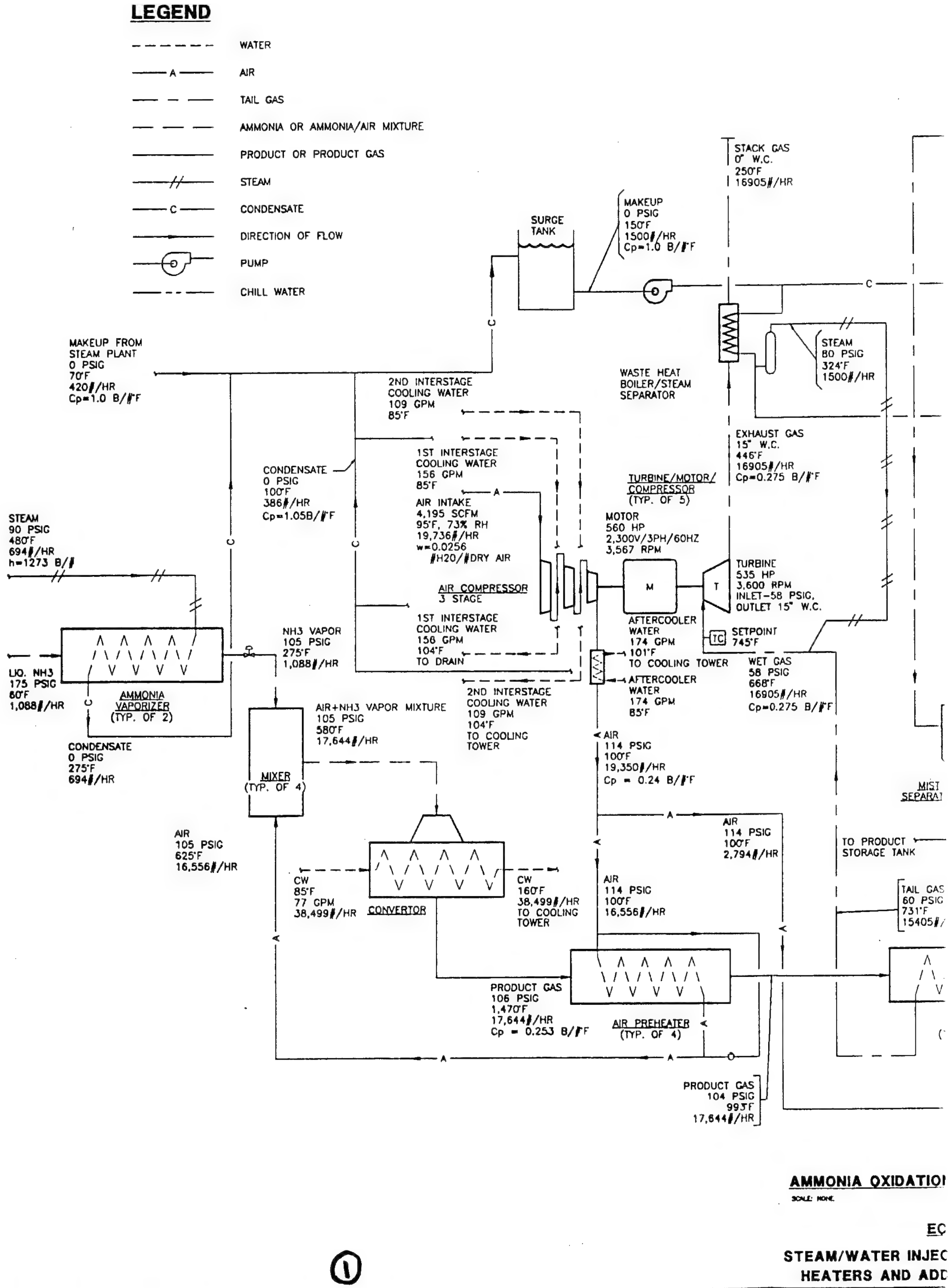
TION ON HEATERS
SURE STEAM RECOVERY

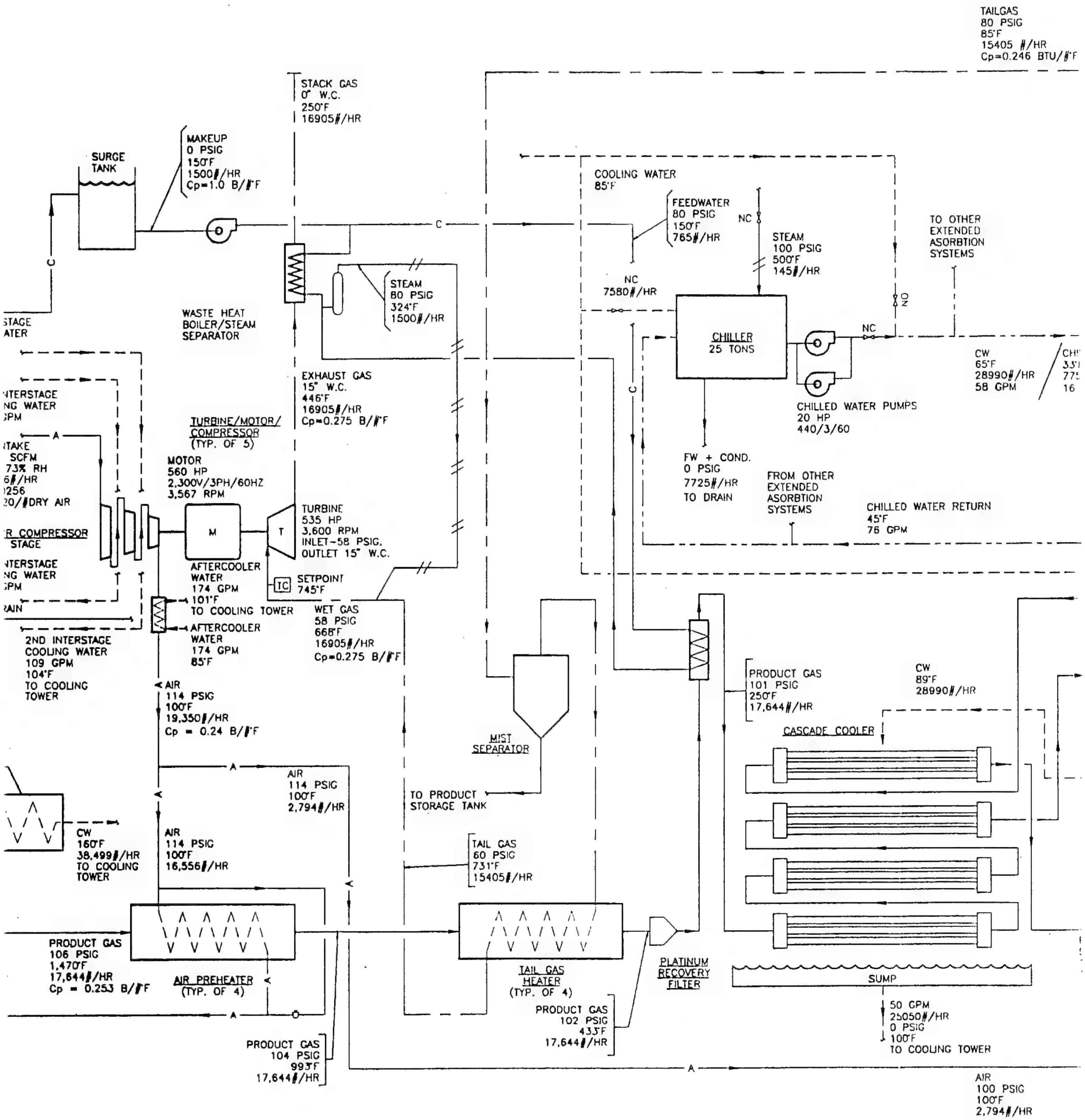
3

TABLE 7. ECO NO. 7 PROCESS ENERGY INVENTORY

Equipment	Heat Gain		Heat Rejected			Heat Recovered			Heat Lost		Remarks
	MBH	Source	MBH	Source	Destination	MBH	Source	Recipient	MBH	Waste Stream	
Ammonia Vaporizer	714.1	L.P. Steam	149.2	Steam Cond.	Tailgas	149.2	Steam Cond.	Tailgas			
Mixer	178.8 (177.9)	Air NH_3									
Converter	7136.1	Reaction	2887.4	Reaction	River Water				2887.4	Drain	
Air Preheater			2128.8	Prod. Gas	Air & Atmos	2086.1	Prod. Gas	Air	42.7	Atmosph.	
Tailgas Heater	2434.7	40% HNO_3 Reaction	2496.7	Prod. Gas & H_2O Vapor Condens.	TG & Atmos	2473.1	Prod. Gas	Tailgas	23.1	Atmosph.	
Prod. Gas Recov. Boiler	608.7	10% HNO_3 Reaction	816.9	Prod. Gas	LP Steam	816.9	Prod. Gas	LP Steam			765 #/hr Steam
Wet Gas Boiler						837.9	Turb Exh.	L.P. Steam	956.6	Stack	786 #/hr Steam
Cascade Cooler	1826.0	30% HNO_3 Reaction	1275.2	Prod. Gas & H_2O Vapor Condens.	River Water Drain & Atmos				1275.2	Drain	
Absorption Columns	1217.3	20% HNO_3 Reaction	86.5	Prod. Gas & H_2O Vapor Condens. & Reaction	River Water				86.5	Drain	
Air Compressor	1425.2	Elect. Meter	2750.6	H_2O Vapor Condens.	River Water				2750.6	Drain	560 hp
Tailgas Turbine	1361.6	Recovered Heat	3156.1	Turbine Exhaust	Wet Gas Recov. Blr	1361.6	Wet Gas	Air			535 hp
Final Bleacher			118.7	Product	Product	118.7	Product	Product			
Unaccounted Losses			859.0						859.0		
TOTAL	16724.6		16724.6			7843.5			8881.1		

Figure 8


LEGEND
WATER
AIR
TAIL GAS
AMMONIA OR AMMONIA/AIR MIXTURE
PRODUCT OR PRODUCT GAS
STEAM
CONDENSATE
DIRECTION OF FLOW
PUMP
CHILL WATER
STACK GAS 0" W.C. 250°F 16905#/HR
MAKEUP 0 PSIG 150°F 1500#/HR Cp=1.0 B/#°F
SURGE TANK
STEAM 80 PSIG 324°F 1500#/HR
WASTE HEAT BOILER/STEAM SEPARATOR
MAKEUP FROM STEAM PLANT 0 PSIG 70°F 420#/HR Cp=1.0 B/#°F
2ND INTERSTAGE COOLING WATER 109 GPM 85°F
EXHAUST GAS 15" W.C. 446°F 16905#/HR Cp=0.275 B/#°F
CONDENSATE 0 PSIG 100°F 386#/HR Cp=1.05B/#°F
1ST INTERSTAGE COOLING WATER 156 GPM 85°F
TURBINE/MOTOR/ COMPRESSOR (TYP. OF 5)
AIR INTAKE 4,195 SCFM 95°F, 73% RH 19,736#/HR w=0.0256 #H20/#DRY AIR
MOTOR 560 HP 2,300V/3PH/60HZ 3,567 RPM
STEAM 90 PSIG 480°F 694#/HR h=1273 B/#
AIR COMPRESSOR 3 STAGE
TURBINE 535 HP 3,600 RPM INLET-58 PSIG, OUTLET 15" W.C.
1ST INTERSTAGE COOLING WATER 156 GPM 104°F TO DRAIN
AFTERCOOLER WATER 174 GPM 101°F TO COOLING TOWER
SETPOINT 745°F
NH3 VAPOR 105 PSIG 275°F 1,088#/HR
WET GAS 58 PSIG 668°F 16905#/HR Cp=0.275 B/#°F
LIQ. NH3 175 PSIG 80°F 1,088#/HR
AMMONIA VAPORIZER (TYP. OF 2)
AFTERCOOLER WATER 174 GPM 85°F
2ND INTERSTAGE COOLING WATER 109 GPM 104°F TO COOLING TOWER
AIR+NH3 VAPOR MIXTURE 105 PSIG 580°F 17,644#/HR
CONDENSATE 0 PSIG 275°F 694#/HR
AIR 114 PSIG 100°F 19,350#/HR Cp = 0.24 B/#°F
MIXER (TYP. OF 4)
MIST SEPARAT
AIR 114 PSIG 100°F 2,794#/HR
TO PRODUCT STORAGE TANK
AIR 105 PSIG 625°F 16,556#/HR
CW 85°F 77 GPM 38,499#/HR
CONVERTOR
CW 160°F 38,499#/HR TO COOLING TOWER
AIR 114 PSIG 100°F 16,556#/HR
TAIL GAS 60 PSIG 731°F 15405#/
PRODUCT GAS 106 PSIG 1,470°F 17,644#/HR Cp = 0.253 B/#°F
AIR PREHEATER (TYP. OF 4)
PRODUCT GAS 104 PSIG 993°F 17,644#/HR
AMMONIA OXIDATIO
SCALE: NONE
EC
STEAM/WATER INJEC
HEATERS AND ADD



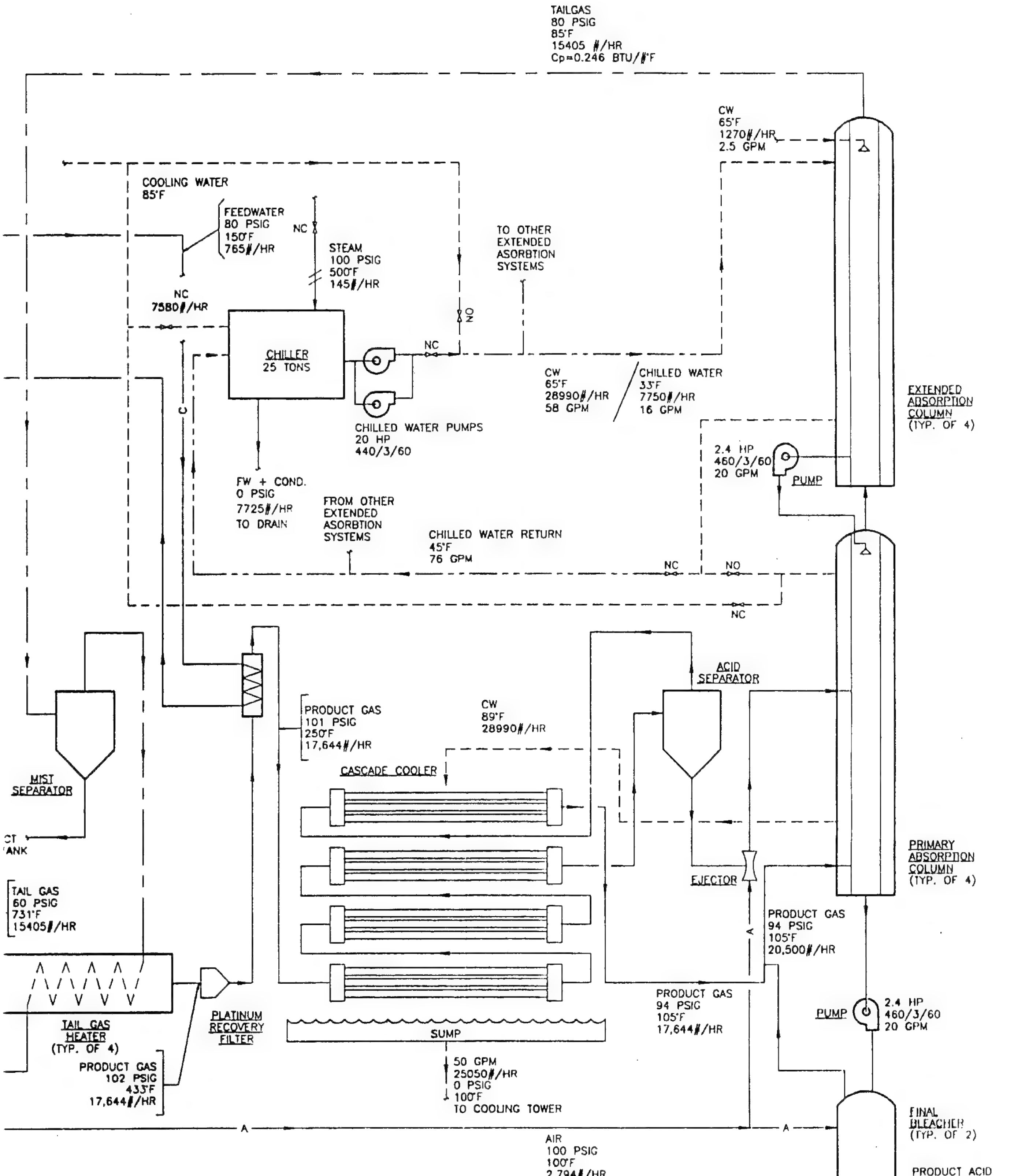
AMMONIA OXIDATION PROCESS FLOW DIAGRAM

SCALE: NONE

ECO NO. 7

2

STEAM/WATER INJECTION AT TAILGAS, INSULATE HEATERS AND ADD WASTE HEAT RECOVERY



DATION PROCESS FLOW DIAGRAM

ECO NO. 7

R INJECTION AT TAILGAS, INSULATE
ND ADD WASTE HEAT RECOVERY

3

Calculations

Calculations for energy inventories throughout the product gas and tailgas flow streams were made using published data where available. Heat release from the exothermic reaction in the product gas stream, as indicated on flow diagrams and tables in the material furnished by the government and the operating contractor, was adjusted by application of principles and chemical values from several engineering handbooks. Excerpts from these handbooks are presented in the Appendix, section Reference Material.

Thermodynamic properties of steam and water vapor in air were obtained from "Thermodynamic Properties of Steam"; thermodynamic properties of air were obtained from "Gas Tables". Specific heat data for various gases and liquids were obtained from "Marks' Standard Handbook for Mechanical Engineers" and additional textbooks. Heat loss for bare and insulated pipes was obtained from insulation manufacturers catalogs. Thermodynamic properties of Dowtherm A heat transfer fluid were obtained from "Marks' Handbook" and from tabular data in Platecoil Catalog, Tranter, Inc. In general, where data was obtained from graphically presented material, the diagram is included in the Appendix with the detailed calculations.

Basic formulae, definitions, numerical values and results of calculations for process chemical and thermal parameters are presented in this section.

Detailed calculation sheets are included in Appendix.

Calculations For: Pound Moles per Hour Delivered to Process

NH_3: $\dfrac{\text{lbs/hr}}{\text{mol. wt}} = \dfrac{1088 \text{ lbs/hr}}{17.0307} = 63.88$ #-mol/hr

Specific Humidity of Air/Vapor Mixture:

$$W = \frac{P_V R_\alpha}{(P_m - P_V) R_V}$$

Where: P_V = Vapor pressure of water @ 100°F dewpoint
P_m = Air/vapor mixture pressure
R_α = Universal gas constant/mol. wt. of air
R_V = Universal gas constant/mol. wt. of H_2O

$$W = \frac{(0.9492 \text{ psia})(1544/28.9644)}{(129.97 \text{ psia} - 0.9492 \text{ psia})(1544/18.016)} = 0.0046 \text{ \#vapor/\#dry air}$$

Air/Vapor Mixture Mass Flow = 16556 lbs/hr

H_2O: $\dfrac{16556 \text{ lbs/hr}}{1 + \dfrac{1}{0.0046 \text{ lbs/\# dry air}}} = 75.81$ lbs/hr

$\dfrac{\text{lbs/hr}}{\text{mol. wt}} = \dfrac{75.81 \text{ lbs/hr}}{18.016} = 4.21$ #-mol/hr

Dry Air Mass Flow = 16556 lbs/hr - 75.81 lbs/hr = 16480.19 lbs/hr

N_2: $\dfrac{\text{lbs/hr x mol. fract}}{\text{mol. wt. air}} = \dfrac{16480.19 \text{ lbs/hr } (0.78084)}{28.9644} = 444.28$ #-mol/hr

O_2: $\dfrac{\text{lbs/hr x mol. fract}}{\text{mol. wt. air}} = \dfrac{16480.19 \text{ lbs/hr } (0.20948)}{28.9644} = 119.19$ #-mol/hr

A_R: $\dfrac{\text{lbs/hr x mol. fract}}{\text{mol. wt. air}} = \dfrac{16480.19 \text{ lbs/hr } (0.00934)}{28.9644} = 5.31$ #-mol/hr

Other: $\dfrac{\text{lbs/hr x mol. fract}}{\text{mol. wt. air}} = \dfrac{16480.19 \text{ lbs/hr } (0.00034)}{28.9644} = 0.19$ #-mol/hr

TOTAL 568.97 #-mol/hr

COMBUSTION CALCULATIONS—MOLAL BASIS

$4NH_3 + 7O_2 \rightarrow 4NO_2 + 6H_2O$

LINE	FUEL CONSTITUENT	PER FUEL UNIT, LB	MOL. WT DIVISOR	MOLES FUEL CONSTITUENT	O_2 MULTIPLIER	O_2 MOLES THEO REQD	NO_2	O_2	N_2	H_2O	CO
	FUEL, O_2, AND AIR PER UNIT OF FUEL						FLUE GAS (F.G.) COMPOSITION MOLES PER FUEL UNIT (AF)				
1	N_2 TO NO_2		28	15.97	2	31.94	31.94				
2	C TO CO		12	0	.5	0					0
3	CO TO CO_2		28	0	.5	0	—				
4	C UNBURNED, LINE k		12	0							
5	H_2		2	47.91	.5	23.96				23.96	
6	S		32	0	1	0	—				
7	O_2 (DEDUCT)		32	0	1	0					
8	N_2		28	—		0			0.00		
9	CO_2		44	0		0	—				
10	H_2O		18	0		0				0	
11	ASH					0					
12	SUM			63.88		55.90					
	O_2 AND AIR, MOLES FOR TOTAL AIR % (SEE LINE d AT RIGHT)										
13	O_2 (THEO) REQD = O_2, LINE 12					55.90					
14	O_2 (EXCESS) = $\frac{T.A. - 100}{100} \times O_2$, LINE 12					0		0			
15	O_2 (TOTAL) SUPPLIED = LINES 13 + 14					55.90					
16	N_2 SUPPLIED = * 3.73 × O_2, LINE 15					208.37			208.37		
17	AIR (DRY) SUPPLIED = O_2 + N_2					264.27					
18	H_2O IN AIR = MOLES DRY AIR × $\frac{A}{B-A}$ *					1.96				1.96	
19	AIR (WET) SUPPLIED = LINES 17 + 18					266.23					
20	FLUE GAS CONSTITUENTS = LINES 1 TO 18, TOTAL						31.94	0	208.37	25.92	0
21	*NOTE—FOR AIR AT 80 F AND 60% RELATIVE HUMIDITY, $\frac{A}{B-A}$ = 0.0212 IS OFTEN USED AS STANDARD. $\frac{0.95}{129.97-0.95} = 0.0074$										

CONDITIONS—ASSIGNED OR OBSERVED AND MISCELLANEOUS

DATE January 4, 1996

	LINE
FUEL NH_3 Ammonia Gas	
SOURCE Vaporizer	
FUEL UNIT { 63.88 Moles, gaseous fuels	
FUEL ANAL. AS FIRED (AF), % BY WT OR VOL	a
N_2 25% by Volume; H_2 75% by Volume	b
CO_2: NEGL. O_2 21% CO NEGL. N_2 78% †	c
TOTAL AIR (T.A.) ASSIGNED or by ORSAT 100 %	d
LINES f, g, h FOR GASEOUS FUELS	e
WT, FUEL UNIT = Σ(MOLES EACH × MOL. WT) LB	f
MOL WT OF FUEL = LINE 17.031	g
SP WT OF FUEL @ 80 F & 29.9" = $\frac{\text{LINE g}}{394}$ $\frac{LB}{CU\ FT}$	h
FUEL HEAT VALUE, BTU/LB CU FT	i
COMBUSTIBLE IN REFUSE, %"C" 0 %	j
CARBON UNBURNED, LB/100 LB FUEL = % ASH IN FUEL × $\frac{\%\text{"C"}}{100 - \%\text{"C"}}$ 0.0	k
EXIT TEMP OF FLUE GAS, t_g — F	l
DRY-BULB (AMBIENT) TEMP, t_a 100 F	m
WET-BULB TEMP 100 F	n
REL HUMID. (PSYCHROMETRIC CHART) 100 %	o
B*, ~~BAROMETRIC~~ PRESSURE, psia 129.97	p
SAT. PRESS. H_2O AT AMB TEMP, IN. 0.95	q
A*, PRESS. H_2O IN AIR, LINES (o × q), 0.95	r

TOTAL MOLES	WET FLUE GAS	DRY FLUE GAS	LINE
	266.23	240.31	s

†NOTE: FLUE GAS ANALYSIS BY ORSAT. IF CO IS PRESENT IN FLUE GASES, A CARBON BALANCE IS USED TO DETERMINE DISTRIBUTION OF C, THUS: ALL C IN FUEL = C IN FLUE GAS CONSTITUENTS + C IN REFUSE. MOLES C IN FUEL = % C BY ANAL. ÷ 12. MOLES C IN REFUSE = LINE k ÷ 12. MOLES C IN CO_2 = (MOLES C IN FUEL − MOLES C IN REFUSE) × % CO_2 BY ORSAT ÷ % CO_2 + CO BY ORSAT.

$$* \frac{\%N_2}{\%O_2} = \frac{78.084}{20.948} = 3.7275$$

COMBUSTION CALCULATIONS—MOLAL BASIS

$N_2 + 2O_2 \rightarrow 2NO_2$

LINE	FUEL CONSTITUENT	PER FUEL UNIT, LB	MOL. WT DIVISOR	MOLES FUEL CONSTITUENT	O_2 MULTIPLIER	O_2 MOLES THEO REQD	FLUE GAS (F.G.) COMPOSITION MOLES PER FUEL UNIT (AF): NO_2	O_2	N_2	H_2O	CO
1	N_2 TO NO_2	—	28	31.65	2	63.29	63.29				
2	C TO CO		12	0	.5	0					0
3	CO TO CO_2		28	0	.5	0	0				
4	C UNBURNED, LINE k		12	0							
5	H_2	—	2	0	.5	0				0	
6	S		32	0	1	0	0				
7	O_2 (DEDUCT)		32	0	1	0					
8	N_2		28	0		0			0.00		
9	CO_2		44	0		0	0				
10	H_2O		18	0		0				0	
11	ASH			0		0					
12	SUM										

O_2 AND AIR, MOLES FOR TOTAL AIR 100 % (SEE LINE d AT RIGHT)

LINE	ITEM	O_2 / AIR MOLES	NO_2	O_2	N_2	H_2O	CO
13	O_2 (THEO) REQD = O_2, LINE 12	63.29					
14	O_2 (EXCESS) = $\frac{T.A. - 100}{100} \times O_2$, LINE 12	0		0			
15	O_2 (TOTAL) SUPPLIED = LINES 13 + 14	63.29					
16	N_2 SUPPLIED = * $(3.73 \times O_2)$ ~~LINE 15~~ minus 31.65	204.26			204.26		
17	AIR (DRY) SUPPLIED = $O_2 + N_2$ (TOTAL)	299.20					
18	H_2O IN AIR = MOLES DRY AIR × $\frac{A}{B-A}$ *	2.21				2.21	
19	AIR (WET) SUPPLIED = LINES 17 + 18	301.41					
20	FLUE GAS CONSTITUENTS = LINES 1 TO 18, TOTAL		63.29	0	204.26	2.21	0

21 *NOTE—FOR AIR AT 80 F AND 60% RELATIVE HUMIDITY, $\frac{A}{B-A}$ = 0.0212 IS OFTEN USED AS STANDARD. $\frac{0.95}{129.97 - 0.95} = 0.0074$

CONDITIONS—ASSIGNED OR OBSERVED AND MISCELLANEOUS

DATE January 4, 1996

		LINE
FUEL SOURCE	N_2 Gas, Air	
FUEL UNIT	31.65 Moles, gaseous fuels	
FUEL ANAL. AS FIRED (AF), % BY WT OR VOL		a
O_2 Avail	Available Oxygen: = 119.19 #-mol/hr − 55.90 #-mol/hr = 63.29 #-mol/hr	b
CO_2 O_2 CO N_2	% [1]	c
TOTAL AIR (T.A.) ASSIGNED or by ORSAT	100 %	d
LINES f, g, h FOR GASEOUS FUELS		e
WT, FUEL UNIT = Σ(MOLES EACH × MOL WT)	LB	f
MOL WT OF FUEL = LINE f ÷ 100	28.013	g
SP WT OF FUEL @ 80 F & 29.9" = $\frac{\text{LINE g}}{394}$	$\frac{LB}{CU\ FT}$	h
FUEL HEAT VALUE, BTU/LB	CU FT	i
COMBUSTIBLE IN REFUSE, % "C"	0 %	j
CARBON UNBURNED, LB/100 LB FUEL = % ASH IN FUEL × $\frac{\%\ "C"}{100 - \%\ "C"}$	0.0	k
EXIT TEMP OF FLUE GAS, t_2	--- F	l
DRY-BULB (AMBIENT) TEMP, t_1	100 F	m
WET-BULB TEMP	100 F	n
REL HUMID. (PSYCHROMETRIC CHART)	100 %	o
B*, ~~BAROMETRIC~~ PRESSURE, psia	129.97	p
SAT. PRESS. H_2O AT AMB TEMP, ~~IN. HG~~	0.95	q
A*, PRESS. H_2O IN AIR, LINES (o × q), ~~IN. HG~~	0.95	r

TOTAL MOLES	WET FLUE GAS	DRY FLUE GAS	LINE
	269.76	267.55	s

[1] NOTE: FLUE GAS ANALYSIS BY ORSAT. IF CO IS PRESENT IN FLUE GASES, A CARBON BALANCE IS USED TO DETERMINE DISTRIBUTION OF C, THUS: ALL C IN FUEL = C IN FLUE GAS CONSTITUENTS + C IN REFUSE. MOLES C IN FUEL = % C BY ANAL. ÷ 12. ... MOLES C IN CO_2 = (MOLES C IN FUEL − MOLES C IN REFUSE) × % CO_2 BY ORSAT ÷ (% CO_2 BY ORSAT + % CO BY ORSAT).

$$* \frac{\%N_2}{\%O_2} = \frac{78.084}{20.948} = 3.7276$$

Calculations For: Theoretical Pound Moles per Hour Product Gas

NO_2: 31.94 #-mol/hr + 63.29 #-mol/hr = 95.23 #mol/hr

N_2: 208.37 #-mol/hr + 204.26 #-mol/hr = 412.63 #mol/hr

H_2O: 25.92 #-mol/hr + 2.21 #-mol/hr = 28.13 #-mol/hr

From Sheet 1:

A_R: $\frac{\text{lbs/hr x mol. fract}}{\text{mol. wt. air}} = \frac{\text{16480.19 lbs/hr (0.00934)}}{28.9644} =$ 5.31 #-mol/hr

Other: $\frac{\text{lbs/hr x mol. fract}}{\text{mol. wt. air}} = \frac{\text{16480.19 lbs/hr (0.00034)}}{28.9644} =$ 0.19 #-mol/hr

TOTAL = 541.49 #-mol/hr

NO_2 Percent by Volume $= \frac{\text{95.23 \#-mol/hr (100)}}{\text{541.49 \#-mol/hr}} =$ 17.59%

N_2 Percent by Volume $= \frac{412.63}{541.49} =$ 76.20%

H_2O Percent by Volume $= \frac{28.13}{541.72} =$ 5.20%

A_R Percent by Volume $= \frac{5.31}{541.49} =$ 0.98%

Other Percent by Volume $= \frac{0.19}{541.72} =$ 0.04%

TOTAL 100.01

Calculations For: Product Gas Specific Heat at Constant Pressure

$$C_{PPRG} = \frac{W_{n2} C_{Pn2} + W_{ar} C_{Par} + W_{NO2} C_{PNO2} + W_{H2O} C_{PH2O}}{W_{PR.G.}}$$

W_{N2}	=	412.63 #moles/hr (28.013)	=	11559.00 #/hr
W_{AR}	=	5.31 #moles/hr (39.948)	=	212.12 #/hr
W_{NO2}	=	95.23 #moles/hr (46.005)	=	4381.06 #/hr
W_{H2O}	=	28.16 #moles/hr (18.015)	=	<u>506.26 #/hr</u>
				16658.94 #/hr

<u>From Gas Table @ 1460° R</u>

$$C_{PN2} = \frac{\varnothing}{\ln T} = \frac{52.867}{\ln 1460} = 7.2558\ ^{B}/\text{\#-mol }^{\circ}F$$

$$C_{PAR} = \frac{\varnothing}{\ln T} = \frac{41.9242}{\ln 1460} = 5.7539\ ^{B}/\text{\#-mol }^{\circ}F$$

$$^{*}C_{PNO2} = \frac{\varnothing}{\ln T} = \frac{61.639}{\ln 1460} = 8.4597\ ^{B}/\text{\#-mol }^{\circ}F$$

$$C_{PH2O} = \frac{\varnothing}{\ln T} = \frac{58.556}{\ln 1460} = 7.3503\ ^{B}/\text{\#-mol }^{\circ}F$$

$$C_{PPR.G.} = \frac{412.63\ (7.2558) + 5.31\ (5.7539) + 95.23\ (7.2558) + 28.13\ (7.3503)}{(541.49 - 0.19)}$$

$$= 7.2460\ ^{B}/\text{\#-mol }^{\circ}F$$

*Assume specific heat of NO_2 (MW = 46) is essentially the same as CO_2 (MW = 44).

Calculations For: Dewpoint of Product Gas

$P_V = H_2O$ mol. fract. x $P_{PG.}$

Where: P_V = vapor pressure of water.
P_{PG} = product gas pressure.

P_V = 0.0520 (102 psig) = 5.304 psig or 20.0 psia

Saturation pressure of H_2O @ 20 psia = 227.96° F

Dewpoint = 227.96° F

<u>Mass Flow of Product Gas Constituents</u>

NO_2 = (#-mol/hr) (#/#-mol) = 95.23 (46.008) = 4381.34 #/hr

N_2 = (#-mol/hr) (#/#-mol) = 416.63 (28.016) = 11672.31 #/hr

H_2O = (#-mol/hr) (#/#-mol) = 28.13 (18.016) = 506.79 #/hr

A_R = (#-mol/hr) (#/#-mol) = 5.31 (39.95) = 16772.57 #/hr

Unaccounted = 17644 - 16773 = 871 #/hr

$$\text{Apparent Mol. Wt.} = \frac{17644 \text{ \#/hr}}{541.49 \text{ \#-mol/hr}} = 32.58 \text{ \#/\#-mol}$$

$$C_P = \frac{7.2460\ ^{B}/\text{\#-mol }^\circ F}{32.58 \text{ \#/\#-mol}} = 0.2224\ ^{B}/\text{\# }^\circ F$$

Calculations For: Recoverable Heat

Q_{REC} $= w\ C_p\ (T_{IN} - T_{OUT}) = 17644\ (0.222)\ (800 - 400)/1000$
$= 1570$ MBH

Assume feedwater entering boiler is 300°F and 65 psig

$W_{STM} = \frac{1570000}{\Delta h} = \frac{1570000}{1183.1 - 282} = 1740$ #/hr @ 65 psig

Volumetric Analysis - Product Gas/Bleaching Air:

Constituent	# Moles/Hr in Blchng Air	# Moles/Hr in Pr. Gas Entg.	# Moles/Hr in New Pr. Gas	% By Volume
N_2	74.93	416.63	491.56	76.57
A	0.90	5.31	6.21	0.97
O_2	20.10	0*	20.10	3.13
NO_2	0	95.23	95.23	14.83
H_2O	0.71	28.13	28.84	4.49
			641.94	99.99

Bleaching Air: 2779 #DA/hr + 15.45 #H_2O/hr = 2794.45 #/hr
moles DA/hr = 2779/28.96 = 95.96

*Assume all available O_2 combines with available N_2:

$N_2 + 2O_2 \text{ -----> } 2NO_2$

Calculations For: Absorption Column Spray Water and Tailgas

Spray Water Required = 40.6 + 3.8 + 31.74 - 28.84 = 47.3 # mol/hr

or $\frac{47.3 \text{ \# mol/hr } (18.016 \text{ \#/\#mol})}{8.33 \text{ \#/g } (60 \text{ m/hr})} = 1.70$ gpm

or 47.3 # mol/hr (18.016 #/#mol) = 855 #/hr

Tail Gas	# Moles/Hr	Mol. Wt.	#/Hr
O_2	20.1	32	643.2
N_2	491.6	28.016	13772.7
NO	31.72	30.008	954.1
H_2O	3.8	18.016	68.5
A_R	6.21	39.948	248.1
Other	0.19	42.09	8.0
	553.62		15694.6

Apparent Mol. Wt. = $\frac{15694.6}{553.62} = 28.349$

Calculations For: 50 Tons/Day of 61% Acid by Volume (66.124 #-mol/hr HNO_3) & Tailgas

Constituent	# Moles Ent. Col	# Moles in Product	# Moles in Tailgas
N_2	491.56	0	491.56
A_R	6.21	0	6.21
O_2	20.10	0	20.10
H_2O	28.84	40.6	3.8
HNO_3	0	63.48	0
NO	0	0	31.74
Reaction: $3NO_2 + H_2O \longrightarrow 2\,HNO_3 + NO$			

Water in Reaction ------> $\frac{95.23}{3} = 31.74$ # moles/hr

Water in Tailgas -----> (Saturated @ 85°F) $\frac{P_V\, R_{TG}}{(P_m - P_V)\, R_V} = \frac{0.5959\ (1544/30)}{(80 - 0.5959)\ (1544/18.016)} = 0.0045$ #/#DTG

Water = 15400 (0.0045) = 69#/hr

Product ----> 63.48 # moles/hr (63.013 #/#mole) + (40.6 #mole/hr) (18.016 #/#mole)

= 4732 #/hr

% HNO_3 $= \frac{63.48\ (100)}{104.1} = 60.98$ by Volume

% HNO_3 $= \frac{63.48\ (63.013)\ (100)}{4732} = 84.5$ by Weight

Calculations For: Product and Tailgas (By Molal Analysis)

Absorption Column Mass Balance:

W_{IN} = 491.56 (28.014) + 6.21 (39.948) + 95.23 (46.01) + 28.84 (18.016) + 855 + 20.1 (32)

= 20418 #/hr

W_{OUT} = 491.56 (28.014) + 6.21 (39.948) + 3.8 (18.016) + 31.74 (30.01) + 20.1 (32) + 4732

= 20415 #/hr

Tailgas = 20415 - 4732 = 15680 #/hr

Calculations For: Tailgas (By Molal Analysis)

$$C_{PTG} = \frac{W_{N2}C_{PN2} + W_{AR}C_{PAR} + W_{NO}C_{PNO} + W_{H2O}C_{PH2O} + W_{O2}C_{PO2}}{W_{TG}}$$

W_{N2} = 491.56 #-Mol/hr

W_{AR} = 6.21 #-Mol/hr

W_{NO} = 31.74 #-Mol/hr

W_{H2O} = 3.8 #-Mol/hr

W_{O2} = 20.1/553.41 #-Mol/hr

Calculate C_P @ 350°F (810°R) - Value of ⌀ from gas tables

$$C_PO_2 = \frac{\varnothing}{\ln T} = \frac{51.911}{\ln 810} = 7.751 \text{ B/\#-Mol°F}$$

$$C_{PN2} = \frac{\varnothing}{\ln T} = \frac{48.61}{\ln 810} = 7.2584 \text{ B/\#-Mol°F}$$

$$C_{PAR} = \frac{\varnothing}{\ln T} = \frac{38.9994}{\ln 810} = 5.8234 \text{ B/\#-Mol°F}$$

$$^*C_{PNO} = \frac{\varnothing}{\ln T} = \frac{50.146}{\ln 810} = 7.4878 \text{ B/\#-Mol°F}$$

$$C_{PH20} = \frac{\varnothing}{\ln T} = \frac{48.419}{\ln 810} = 7.2299 \text{ B/\#-Mol°F}$$

$$C_{PTG} = \frac{491.56\ (7.2584) + 6.21\ (5.8234) + 31.74\ (7.4878) + 3.8\ (7.2299) + 20.1\ (7.7513)}{553.41}$$

7.2732 B/#-Mol°F

or

$$\frac{7.2732 \text{ B/\#-Mol°F } (553.41 \text{ \#-Mol/hr})}{15680 \text{ \#/hr}} = 0.257 \text{ B/\#°F}$$

Cost Data

"Means Mechanical Cost Data", 19th Annual Edition, 1996 was used for unit price data for the majority of line items entered on estimating forms. Pipe fittings and accessories were entered as ±80 percent of run-of-pipe cost. Major equipment pricing, where not included in "Means", was developed from published cost of similar devices tempered by engineering judgement.

ECO costs were developed for a single process line, including equipment shown on the Process Flow Diagrams. Provisions for "Crossover" to permit any one of the five air compressors, for instance, is not included, nor is the provision to interconnect any other new device in one process line with its companion device in an adjacent process line. Additional expenditures to implement similar changes on a second line will not produce additional savings at the present production rate.

Cost estimate analysis sheets for each ECO are included in this section, followed by Life Cycle Analysis Summary sheets from the LCIDD computer program.

Cost analysis rough worksheets are presented in Appendix.

COST ESTIMATE ANALYSIS

DATE PREPARED: 11/14/95

ESTIMATOR: PDL

PROJECT: HOLSTON AAP AREA B NITRIC ACID | **LOCATION:** KINGSPORT, TENNESSEE

TASK DESCRIPTION	QUANTITY		LABOR		EQUIPMENT		MATERIAL		
ECO NO. 1	NO OF UNITS	UNIT MEAS	UNIT PRICE	COST	UNIT PRICE	COST	UNIT PRICE	COST	TOTAL
STEAM PIPING:									
6" ⌀ Sch.40 Undrgr.	250	LF	16.55	4138	1.28	320	31.00	7750	$12,208.00
3" ⌀ Sch. 80 Undrgr.	250	LF	17.65	4413	1.28	320	19.50	4875	9608.00
4" ⌀ Sch. 40	150	LF	11.70	1755	1.40	210	10.60	1590	3555.00
2" ⌀ Sch. 80	150	LF	7.75	1163	.86	129	5.50	837	2129.00
Pipe Insul.	300	LF		2000				1000	3000.00
Turbin Mod. Cost		LS		10000				10000	20000.00
15000#/Hr. Stm. Surf. Cndns.	1	EA		10000		2500		30000	42500.00
Cond. Pump	1	EA		300				1500	1800.00
8" Condnsr Wtr. Piping	300	LF	23	6900	1.81	543	31.00	9300	16743.00
Pipe Ftgs & Misc.	1	LOT		10000				25000	35000.00
TOTAL				**50669**		**4022**		**91852**	**$146,543.00**

COST ESTIMATE ANALYSIS										DATE PREPARED: 11/14/95 ESTIMATOR: PDL
PROJECT: HOLSTON AAP AREA B NITRIC ACID					**LOCATION:** KINGSPORT, TENNESSEE					
TASK DESCRIPTION	QUANTITY		LABOR		EQUIPMENT		MATERIAL			
ECO NO. 2	NO OF UNITS	UNIT MEAS	UNIT PRICE	COST	UNIT PRICE	COST	UNIT PRICE	COST	TOTAL	
STEAM PIPING:										
8" ⌀ Sch.40 Undrgr.	250	LF	17.40	4350	1.28	320	33.50	8375	$13,045.00	
3" ⌀ Sch. 80 Undrgr.	250	LF	17.65	4413	1.28	320	19.50	4875	9608.00	
8" ⌀ Sch. 40	150	LF	23.00	3450	1.81	272	31.00	4650	8372.00	
2" ⌀ Sch. 80	150	LF	7.75	1163	.86	129	5.50	837	2129.00	
Pipe Insul.	1	LOT		2500				1200	3700.00	
DOWTHERM PIPE:										
2 1/2" ⌀ Sch. 40	200	LF	9.20	1840	1.12	224	6.40	1280	3344.00	
Pipe Insul.	1	LOT		2000				1000	3000.00	
Hi Temp Pump (406 GPM)	1	EA		300				3438	3738.00	
65 GPM Pump	1	EA		216				1375	1591.00	
N_2 Blnkt. Syst.	1	EA		250				1000	1250.00	
Unfired Blr. Vessel	1	EA		5000		2500		75000	82500.00	
Misc. Acces. & Fittings	1	LOT		20000				40000	60000.00	
TOTAL				**45482**		**3765**		**143030**	**$192,277.00**	

COST ESTIMATE ANALYSIS										DATE PREPARED: 11/14/95 ESTIMATOR: PDL
PROJECT: HOLSTON AAP AREA B NITRIC ACID						LOCATION: KINGSPORT, TENNESSEE				
TASK DESCRIPTION	QUANTITY		LABOR		EQUIPMENT		MATERIAL			
ECO NO. 3	NO OF UNITS	UNIT MEAS	UNIT PRICE	COST	UNIT PRICE	COST	UNIT PRICE	COST	TOTAL	
FIBERGLASS COOLING TOWER										
600 GPM Ind. Dr.	1	EA		1500		1000		12000	$14,500.00	
Pumps & Piping	1	LOT		3500				7200	10700.00	
Elect		LS		3000				5000	8000.00	
Sitework/Pads		LS		5000				1000	6000.00	
TOTAL				**13000**		**1000**		**25200**	39,200.00	

COST ESTIMATE ANALYSIS							DATE PREPARED: 11/14/95 ESTIMATOR: PDL
PROJECT: HOLSTON AAP AREA B NITRIC ACID					LOCATION: KINGSPORT, TENNESSEE		
TASK DESCRIPTION	QUANTITY		LABOR		MATERIAL		
Insulation ECO NO. 4	NO OF UNITS	UNIT MEAS	UNIT PRICE	COST	UNIT PRICE	COST	TOTAL
1" CALCIUM SILICATE:							
18" ⌀ Air Preheater	12	LF	5.40	64.80	9.35	112.20	$ 177.00
18" ⌀ Tailgas Heater	25	LF	5.40	135.00	9.35	233.75	368.75
8" ⌀ Tailgas Pipe to Turbine	120	LF	3.84	460.80	4.26	511.20	972.00
0.010 S.S. JACKET:							
18" ⌀ Air Preheater	60	SF	4.03	241.80	.93	55.80	297.60
18" ⌀ Tailgas Heater	125	SF	4.03	503.75	.93	116.25	620.00
8" ⌀ Tailgas Pipe to Turbine	315	SF	4.03	1,269.45	.93	292.95	1,562.40
18" ⌀ Flange Sets (Insulation)	10	SF	13.45	134.50	2.71	27.10	$161.60
18" ⌀ Flange Sets (Jacket)	10	SF	4.03	40.30	.93	9.30	$49.60
Subtotal			$2,850.40			$1,358.55	$ 4,208.95
15% Conting							631.35
TOTAL Construction Use							**$ 4,850.00**

COST ESTIMATE ANALYSIS							DATE PREPARED: 11/14/95 ESTIMATOR: PDL
PROJECT: HOLSTON AAP AREA B NITRIC ACID					LOCATION: KINGSPORT, TENNESSEE		
TASK DESCRIPTION ECO NO. 5	**QUANTITY**		**LABOR**		**MATERIAL**		**TOTAL**
	NO OF UNITS	UNIT MEAS	UNIT PRICE	COST	UNIT PRICE	COST	
18" Semicircular							
Plate Heat Exchanger 14' Long	1	EA		100.00		5,000.00	$ 5,100.00
Clayton Whsg. Waste							
Heat Steam Generator	1	EA		2,000.00		5,000.00	7,000.00
Condensate Cooler	1	EA		100.00		500.00	600.00
Cond. Rcvr/Pump	1	EA		300.00		1,500.00	1,800.00
1-1/4" ⌀ Insulated							
Pipe & Fittings	1	LOT		7,500.00		5,000.00	$12,500.00
TOTAL				**10,000.00**		**17,000.00**	**$ 27,000.00**

COST ESTIMATE ANALYSIS									DATE PREPARED: 11/14/95 ESTIMATOR: PDL
PROJECT: HOLSTON AAP AREA B NITRIC ACID				LOCATION: KINGSPORT, TENNESSEE					
TASK DESCRIPTION	**QUANITY**		**LABOR**		**EQUIPMENT**		**MATIERIAL**		
ECO NO. 7	NO OF UNITS	UNIT MEAS	UNIT PRICE	COST	UNIT PRICE	COST	UNIT PRICE	COST	**TOTAL**
Makeup & Fowtr. Pipe - 1" ⌀	500	LF	4.65	4138	.57	285	2.89	1445.00	$4,055.00
Steam Pipe - 1-1/2" ⌀	150	LF	5.70	4413	.69	104	3.96	594.00	1,553.00
400 Series St. Stl. Econom.	1	EA		1755		500		185500.00	188,000.00
Waste Ht. Blr. System	1	EA		1,500		150		68600.00	70,250.00
Fdwtr Pump-46 PM/225 TDH	1	EA	72.50	1163			500	500.00	573.00
Temperature Controls	1	SET	150.00	2000			850	850.00	1,000.00
6"⌀ A3126RTP321 Pipe	40	LF	20.00	10000	1.50	60	60	2400.00	3,260.00
Heater Insulation		LS		300				1360.00	4,210.00
Steam Pipe Insul	150	LF	2.49	6900			2.23	335.00	709.00
Fdwtr Pipe Insul	150	LF	2.42	10000			2.16	324.00	687.00
Surge Tank - 100 Gag	1	EA		25				100.00	$125.00
Pipe Fittings & Accos.	1	LOT		2000				5500.00	$7,500.00
Subtotal				13,315			1,099	267508.00	$281,922.00
**Cost W.O. St. Stl. Sect.									**$93,922.00**

LIFE CYCLE COST ANALYSIS SUMMARY STUDY: 95094
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP) LCCID 1.080
INSTALLATION & LOCATION: HOLSTON ARMY AREGION NOS. 4 CENSUS: 3
PROJECT NO. & TITLE: 95094 AREA B NITRIC ACID PRODUCTION FACILITY
FISCAL YEAR 1996 DISCRETE PORTION NAME: ECO #1 STM. TURB.DRIVE @ AIR COMPR.
ANALYSIS DATE: 12-21-95 ECONOMIC LIFE 20 YEARS PREPARED BY: LITTLE

1. INVESTMENT

A. CONSTRUCTION COST	$ 146543.		
B. SIOH	$ 14661.		
C. DESIGN COST	$ 15993.		
D. TOTAL COST (1A+1B+1C)	$ 177197.		
E. SALVAGE VALUE OF EXISTING EQUIPMENT		$ 0.	
F. PUBLIC UTILITY COMPANY REBATE		$ 0.	
G. TOTAL INVESTMENT (1D - 1E - 1F)			$ 177197.

2. ENERGY SAVINGS (+) / COST (-)
DATE OF NISTIR 85-3273-X USED FOR DISCOUNT FACTORS OCT 1993

FUEL	UNIT COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELECT	$ 10.25	2325.	$ 23831.	15.61	$ 372001.
B. DIST	$ .00	0.	$ 0.	17.56	$ 0.
C. RESID	$ .00	0.	$ 0.	19.97	$ 0.
D. NAT G	$ .00	0.	$ 0.	20.96	$ 0.
E. COAL	$ .00	0.	$ 0.	17.58	$ 0.
F. LPG	$ .00	0.	$ 0.	16.12	$ 0.
L. OTHER	$ 3.90	-10538.	$ -41097.	14.74	$ -605775.
M. DEMAND SAVINGS			$ 13050.	14.74	$ 192357.
N. TOTAL		-8213.	$ -4216.		$ -41417.

3. NON ENERGY SAVINGS(+) / COST(-)

A. ANNUAL RECURRING (+/-) $ 0.
(1) DISCOUNT FACTOR (TABLE A) 14.74
(2) DISCOUNTED SAVING/COST (3A X 3A1) $ 0.

B. NON RECURRING SAVINGS(+) / COSTS(-)

ITEM	SAVINGS(+) COST(-) (1)	YR OC (2)	DISCNT FACTR (3)	DISCOUNTED SAVINGS(+)/ COST(-)(4)
d. TOTAL	$ 0.			0.

C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+)/COST(-)(3A2+3Bd4)$ 0.

4. FIRST YEAR DOLLAR SAVINGS 2N3+3A+(3Bd1/(YRS ECONOMIC LIFE))$ -4216.

5. SIMPLE PAYBACK PERIOD (1G/4) -42.03 YEARS

6. TOTAL NET DISCOUNTED SAVINGS (2N5+3C) $ -41417.

7. SAVINGS TO INVESTMENT RATIO (SIR)=(6 / 1G)= -.23
(IF < 1 PROJECT DOES NOT QUALIFY)

**** Project does not qualify for ECIP funding; 4,5,6 for information only.

8. ADJUSTED INTERNAL RATE OF RETURN (AIRR): N/A

LIFE CYCLE COST ANALYSIS SUMMARY STUDY: 95094
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP) LCCID 1.080
INSTALLATION & LOCATION: HOLSTON ARMY AREGION NOS. 4 CENSUS: 3
PROJECT NO. & TITLE: 95094 AREA B NITRIC ACID PRODUCTION FACILITY
FISCAL YEAR 1996 DISCRETE PORTION NAME: ECO #2 REJCTD HT CNVRTD TO 100# STM
ANALYSIS DATE: 12-21-95 ECONOMIC LIFE 20 YEARS PREPARED BY: LITTLE

1. INVESTMENT

A. CONSTRUCTION COST	$	192275.
B. SIOH	$	10576.
C. DESIGN COST	$	11537.
D. TOTAL COST (1A+1B+1C)	$	214388.
E. SALVAGE VALUE OF EXISTING EQUIPMENT	$	0.
F. PUBLIC UTILITY COMPANY REBATE	$	0.
G. TOTAL INVESTMENT (1D - 1E - 1F)	$	214388.

2. ENERGY SAVINGS (+) / COST (-)
DATE OF NISTIR 85-3273-X USED FOR DISCOUNT FACTORS OCT 1993

FUEL	UNIT COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELECT	$ 10.25	-885.	$ -9071.	15.61	$ -141602.
B. DIST	$ .00	0.	$ 0.	17.56	$ 0.
C. RESID	$ .00	0.	$ 0.	19.97	$ 0.
D. NAT G	$ .00	0.	$ 0.	20.96	$ 0.
E. COAL	$ .00	0.	$ 0.	17.58	$ 0.
F. LPG	$ .00	0.	$ 0.	16.12	$ 0.
L. OTHER	$ 3.90	3445.	$ 13436.	14.74	$ 198039.
M. DEMAND SAVINGS			$ -1855.	14.74	$ -27343.
N. TOTAL		2560.	$ 2509.		$ 29094.

3. NON ENERGY SAVINGS(+) / COST(-)

A. ANNUAL RECURRING (+/-) $ -1080.
(1) DISCOUNT FACTOR (TABLE A) 14.74
(2) DISCOUNTED SAVING/COST (3A X 3A1) $ -15919.

B. NON RECURRING SAVINGS(+) / COSTS(-)

ITEM	SAVINGS(+) COST(-) (1)	YR OC (2)	DISCNT FACTR (3)	DISCOUNTED SAVINGS(+)/ COST(-)(4)
d. TOTAL	$ 0.			0.

C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+)/COST(-)(3A2+3Bd4)$ -15919.

4. FIRST YEAR DOLLAR SAVINGS 2N3+3A+(3Bd1/(YRS ECONOMIC LIFE))$ 1429.

5. SIMPLE PAYBACK PERIOD (1G/4) 150.00 YEARS

6. TOTAL NET DISCOUNTED SAVINGS (2N5+3C) $ 13175.

7. SAVINGS TO INVESTMENT RATIO (SIR)=(6 / 1G)= .06
(IF < 1 PROJECT DOES NOT QUALIFY)

8. ADJUSTED INTERNAL RATE OF RETURN (AIRR): -10.32 %

LIFE CYCLE COST ANALYSIS SUMMARY STUDY: 95094
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP) LCCID 1.080
INSTALLATION & LOCATION: HOLSTON ARMY AREGION NOS. 4 CENSUS: 3
PROJECT NO. & TITLE: 95094 AREA B NITRIC ACID PRODUCTION FACILITY
FISCAL YEAR 1996 DISCRETE PORTION NAME: ECO #3 REDUCED WTR CONSUMP W/ CLNG TWR
ANALYSIS DATE: 12-21-95 ECONOMIC LIFE 20 YEARS PREPARED BY: LITTLE

1. INVESTMENT

A. CONSTRUCTION COST	$ 39200.		
B. SIOH	$ 2156.		
C. DESIGN COST	$ 2352.		
D. TOTAL COST (1A+1B+1C)	$ 43708.		
E. SALVAGE VALUE OF EXISTING EQUIPMENT		$ 0.	
F. PUBLIC UTILITY COMPANY REBATE		$ 0.	
G. TOTAL INVESTMENT (1D - 1E - 1F)			$ 43708.

2. ENERGY SAVINGS (+) / COST (-)
DATE OF NISTIR 85-3273-X USED FOR DISCOUNT FACTORS OCT 1993

FUEL	UNIT COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELECT	$ 10.25	-65.	$ -666.	15.61	$ -10400.
B. DIST	$ .00	0.	$ 0.	17.56	$ 0.
C. RESID	$ .00	0.	$ 0.	19.97	$ 0.
D. NAT G	$ .00	0.	$ 0.	20.96	$ 0.
E. COAL	$ .00	0.	$ 0.	17.58	$ 0.
F. LPG	$ .00	0.	$ 0.	16.12	$ 0.
M. DEMAND SAVINGS			$ 0.	14.74	$ 0.
N. TOTAL		-65.	$ -666.		$ -10400.

3. NON ENERGY SAVINGS(+) / COST(-)

A. ANNUAL RECURRING (+/-) $ 5524.
(1) DISCOUNT FACTOR (TABLE A) 14.74
(2) DISCOUNTED SAVING/COST (3A X 3A1) $ 81424.

B. NON RECURRING SAVINGS(+) / COSTS(-)

ITEM	SAVINGS(+) COST(-) (1)	YR OC (2)	DISCNT FACTR (3)	DISCOUNTED SAVINGS(+)/ COST(-)(4)
d. TOTAL	$ 0.			0.

C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+)/COST(-)(3A2+3Bd4)$ 81424.

4. FIRST YEAR DOLLAR SAVINGS 2N3+3A+(3Bd1/(YRS ECONOMIC LIFE))$ 4858.

5. SIMPLE PAYBACK PERIOD (1G/4) 9.00 YEARS

6. TOTAL NET DISCOUNTED SAVINGS (2N5+3C) $ 71024.

7. SAVINGS TO INVESTMENT RATIO (SIR)=(6 / 1G)= 1.62
(IF < 1 PROJECT DOES NOT QUALIFY)

**** Project does not qualify for ECIP funding; 4,5,6 for information only.

8. ADJUSTED INTERNAL RATE OF RETURN (AIRR): N/A

LIFE CYCLE COST ANALYSIS SUMMARY STUDY: 95094
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP) LCCID 1.080
INSTALLATION & LOCATION: HOLSTON ARMY AREGION NOS. 4 CENSUS: 3
PROJECT NO. & TITLE: 95094 AREA B NITRIC ACID PRODUCTION FACILITY
FISCAL YEAR 1996 DISCRETE PORTION NAME: ECO #4 INSULATE HEAT EXCHANGERS
ANALYSIS DATE: 12-21-95 ECONOMIC LIFE 20 YEARS PREPARED BY: LITTLE

1. INVESTMENT

A. CONSTRUCTION COST	$ 4850.		
B. SIOH	$ 267.		
C. DESIGN COST	$ 291.		
D. TOTAL COST (1A+1B+1C)	$ 5408.		
E. SALVAGE VALUE OF EXISTING EQUIPMENT		$ 0.	
F. PUBLIC UTILITY COMPANY REBATE		$ 0.	
G. TOTAL INVESTMENT (1D - 1E - 1F)			$ 5408.

2. ENERGY SAVINGS (+) / COST (-)
DATE OF NISTIR 85-3273-X USED FOR DISCOUNT FACTORS OCT 1993

FUEL	UNIT COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELECT	$ 10.25	460.	$ 4718.	15.61	$ 73656.
B. DIST	$ .00	0.	$ 0.	17.56	$ 0.
C. RESID	$ .00	0.	$ 0.	19.97	$ 0.
D. NAT G	$ .00	0.	$ 0.	20.96	$ 0.
E. COAL	$ .00	0.	$ 0.	17.58	$ 0.
F. LPG	$ .00	0.	$ 0.	16.12	$ 0.
M. DEMAND SAVINGS			$ 2585.	14.74	$ 38103.
N. TOTAL		460.	$ 7303.		$ 111758.

3. NON ENERGY SAVINGS(+) / COST(-)

A. ANNUAL RECURRING (+/-)		$ 0.
(1) DISCOUNT FACTOR (TABLE A)	14.74	
(2) DISCOUNTED SAVING/COST (3A X 3A1)		$ 0.

B. NON RECURRING SAVINGS(+) / COSTS(-)

ITEM	SAVINGS(+) COST(-) (1)	YR OC (2)	DISCNT FACTR (3)	DISCOUNTED SAVINGS(+)/ COST(-)(4)
d. TOTAL	$ 0.			0.

C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+)/COST(-)(3A2+3Bd4)$ 0.

4. FIRST YEAR DOLLAR SAVINGS 2N3+3A+(3Bd1/(YRS ECONOMIC LIFE))$ 7303.

5. SIMPLE PAYBACK PERIOD (1G/4) .74 YEARS

6. TOTAL NET DISCOUNTED SAVINGS (2N5+3C) $ 111758.

7. SAVINGS TO INVESTMENT RATIO (SIR)=(6 / 1G)= 20.67
(IF < 1 PROJECT DOES NOT QUALIFY)

8. ADJUSTED INTERNAL RATE OF RETURN (AIRR): 19.96 %

LIFE CYCLE COST ANALYSIS SUMMARY   STUDY: 95094
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)   LCCID 1.080
INSTALLATION & LOCATION: HOLSTON ARMY AREGION NOS. 4 CENSUS: 3
PROJECT NO. & TITLE: 95094   AREA B NITRIC ACID PRODUCTION FACILITY
FISCAL YEAR 1996   DISCRETE PORTION NAME: ECO #5 INSUL HX S W/ NEW 30# STM SYST
ANALYSIS DATE: 12-21-95 ECONOMIC LIFE 20 YEARS PREPARED BY: LITTLE

1. INVESTMENT

A. CONSTRUCTION COST	$ 31850.	
B. SIOH	$ 1752.	
C. DESIGN COST	$ 1911.	
D. TOTAL COST (1A+1B+1C)	$ 35513.	
E. SALVAGE VALUE OF EXISTING EQUIPMENT	$ 0.	
F. PUBLIC UTILITY COMPANY REBATE	$ 0.	
G. TOTAL INVESTMENT (1D - 1E - 1F)		$ 35513.

2. ENERGY SAVINGS (+) / COST (-)
DATE OF NISTIR 85-3273-X USED FOR DISCOUNT FACTORS OCT 1993

FUEL	UNIT COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELECT	$ 10.25	460.	$ 4718.	15.61	$ 73656.
B. DIST	$ .00	0.	$ 0.	17.56	$ 0.
C. RESID	$ .00	0.	$ 0.	19.97	$ 0.
D. NAT G	$ .00	0.	$ 0.	20.96	$ 0.
E. COAL	$ .00	0.	$ 0.	17.58	$ 0.
F. LPG	$ .00	0.	$ 0.	16.12	$ 0.
L. OTHER	$ 3.90	664.	$ 2589.	14.74	$ 38159.
M. DEMAND SAVINGS			$ 2585.	14.74	$ 38103.
N. TOTAL		1124.	$ 9892.		$ 149918.

3. NON ENERGY SAVINGS(+) / COST(-)

A. ANNUAL RECURRING (+/-) $ -132.
(1) DISCOUNT FACTOR (TABLE A)   14.74
(2) DISCOUNTED SAVING/COST (3A X 3A1) $ -1946.

B. NON RECURRING SAVINGS(+) / COSTS(-)

ITEM	SAVINGS(+) COST(-) (1)	YR OC (2)	DISCNT FACTR (3)	DISCOUNTED SAVINGS(+)/ COST(-)(4)
d. TOTAL	$ 0.			0.

C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+)/COST(-)(3A2+3Bd4)$ -1946.

4. FIRST YEAR DOLLAR SAVINGS 2N3+3A+(3Bd1/(YRS ECONOMIC LIFE))$ 9760.

5 SIMPLE PAYBACK PERIOD (1G/4)   3.64 YEARS

6. TOTAL NET DISCOUNTED SAVINGS (2N5+3C) $ 147972.

7. SAVINGS TO INVESTMENT RATIO   (SIR)=(6 / 1G)=   4.17
(IF < 1 PROJECT DOES NOT QUALIFY)

8. ADJUSTED INTERNAL RATE OF RETURN (AIRR):   10.73 %

LIFE CYCLE COST ANALYSIS SUMMARY STUDY: 95094
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP) LCCID 1.080
INSTALLATION & LOCATION: HOLSTON ARMY AREGION NOS. 4 CENSUS: 3
PROJECT NO. & TITLE: 95094 AREA B NITRIC ACID PRODUCTION FACILITY
FISCAL YEAR 1996 DISCRETE PORTION NAME: ECO #7 RECOVERED STM INJECT @ TLGS TURB
ANALYSIS DATE: 12-22-95 ECONOMIC LIFE 20 YEARS PREPARED BY: LITTLE

1. INVESTMENT

A. CONSTRUCTION COST	$ 281920.		
B. SIOH	$ 4125.		
C. DESIGN COST	$ 4500.		
D. TOTAL COST (1A+1B+1C)	$ 290545.		
E. SALVAGE VALUE OF EXISTING EQUIPMENT		$ 0.	
F. PUBLIC UTILITY COMPANY REBATE		$ 0.	
G. TOTAL INVESTMENT (1D - 1E - 1F)			$ 290545.

2. ENERGY SAVINGS (+) / COST (-)
DATE OF NISTIR 85-3273-X USED FOR DISCOUNT FACTORS OCT 1993

FUEL	UNIT COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELECT	$ 10.25	683.	$ 7002.	15.61	$ 109304.
B. DIST	$ .00	0.	$ 0.	17.56	$ 0.
C. RESID	$ .00	0.	$ 0.	19.97	$ 0.
D. NAT G	$ .00	0.	$ 0.	20.96	$ 0.
E. COAL	$ .00	0.	$ 0.	17.58	$ 0.
F. LPG	$ .00	0.	$ 0.	16.12	$ 0.
M. DEMAND SAVINGS			$ 3835.	14.74	$ 56528.
N. TOTAL		683.	$ 10837.		$ 165832.

3. NON ENERGY SAVINGS(+) / COST(-)

A. ANNUAL RECURRING (+/-) $ -412.
(1) DISCOUNT FACTOR (TABLE A) 14.74
(2) DISCOUNTED SAVING/COST (3A X 3A1) $ -6073.

B. NON RECURRING SAVINGS(+) / COSTS(-)

ITEM	SAVINGS(+) COST(-) (1)	YR OC (2)	DISCNT FACTR (3)	DISCOUNTED SAVINGS(+)/ COST(-)(4)
d. TOTAL	$ 0.			0.

C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+)/COST(-)(3A2+3Bd4)$ -6073.

4. FIRST YEAR DOLLAR SAVINGS 2N3+3A+(3Bd1/(YRS ECONOMIC LIFE))$ 10425.

5. SIMPLE PAYBACK PERIOD (1G/4) 27.87 YEARS

6. TOTAL NET DISCOUNTED SAVINGS (2N5+3C) $ 159759.

7. SAVINGS TO INVESTMENT RATIO (SIR)=(6 / 1G)= .55
(IF < 1 PROJECT DOES NOT QUALIFY)

8. ADJUSTED INTERNAL RATE OF RETURN (AIRR): .06 %

Pg 55

Extracted to

Go with

Executive Summary

4/19/96

Conclusion

Four of the six ECO's evaluated produce savings to investment ratios greater than 1.25. Not all of these conservation concepts can be accomplished simultaneously. ECO No. 5 is predicated on being incorporated with No. 4, and these two concepts should be considered as one.

Neither ECO No. 1 nor No. 2 is compatible with ECO No. 5, since each of them negates the availability of high energy tailgas on which ECO No. 5 depends.

ECO No. 3 can be incorporated with any combination of other mutually compatible ECO's.

Although integral implementation of ECO's No. 1 and No. 2 could be accomplished, this combination can be eliminated by inspection because No. 1 requires increased steam flow from the central plant at 300 psig, while No. 2 produces excess 100 psig steam to displace central plant steam.

The available groupings of qualifying ECO's do not produce an aggregate cost greater than $300,000, and therefore cannot be considered for ECIP funding.

We recommend implementation of ECO's No. 7, which at current production rates, will produce calculated electrical savings of 683 x 10^6 Btu/yr $3,835 per year in electrical demand costs.

Abbreviations

AESE: Affiliated Engineers SE, Inc.

AOP: Ammonia Oxidation Process

ASME: American Society of Mechanical Engineers

bhp: Boiler Horsepower

ECO: Energy Conservation Opportunity

(ECIP): Energy Conservation Investment Program. This is a federal government program which allocates funds for projects which increase energy efficiency.

HDC: Holston Defense Corporation

HAAP: Holston Army Ammunition Plant

Excess Air: A term used to describe the amount of air that is supplied to fossil fired boilers over and above the amount theoretically required for complete combustion.

hr/yr: hour per year

kWh: kilowatt-hour

lb/hr: pounds per hour

lb/mo: pounds per month

(LCCID): Life Cycle Cost in Design. Government software package used to evaluate projects for ECIP funding.

MBtu/hr: thousand British thermal units per hour

MMBtu/yr: million British thermal units per year

psig: pounds per square inch gauge

SIR: Savings to Investment Ratio

Appendices

DETAILED CALCULATIONS

AFFILIATED ENGINEERS SE, INC.
3300 SW Archer Road
Gainesville, Florida 32608
(904) 376-5500
FAX (904) 375-3479

Made By:	Date:	Job No:
PDL		95094-00
Checked By:	Date:	Sheet No: 1 of

Calculations For: VOLUMETRIC ANALYSIS OF PRODUCT GAS

COMPOSITE MOLECULAR WIEGHT OF AIR = 28.96 (FROM MARKS HNDBK)

DRY AIR SUPPLIED = $\frac{16465 \text{ \#/HR}}{28.96 \text{ \#/\#MOLE}}$ = 568.54 #MOLES/HR

AMMONIA SUPPLIED = $\frac{1088 \text{ \#/HR}}{17.032 \text{ \#/\#MOLE}}$ = 63.88 #MOLES/HR

AMMONIA OXIDATION:

$$4NH_3 + 7O_2 \longrightarrow 4NO_2 + 6H_2O$$

APPARENT ADDITIONAL N_2 OXIDATION:

$$N_2 + 2O_2 \longrightarrow 2NO_2$$

FROM MARKS HNDBK

OXYGEN SUPPLIED = (568.54 #MOLES/HR)$\left(\frac{20.948}{100}\right)$ = 119.10 #MOLES/HR

O_2 USED IN 100% OXIDATION OF NH_3 = 63.88 #MOLES/HR $\left(\frac{7}{4}\right)$ = 111.79 #MOLES/HR

O_2 USED IN N_2 OXIDATION = 119.10 − 111.79 = 7.31 #MOLES/HR

NO_2 IN PROD. GAS = 63.88$\left(\frac{4}{4}\right)$ + 7.31$\left(\frac{2}{2}\right)$ = 71.19 #MOLES/HR

N_2 USED IN N_2 OXIDATION = $\frac{7.31}{2}$ = 3.66 #MOLES/HR.

H_2O FROM NH_3 OXIDATION = 63.88$\left(\frac{6}{4}\right)$ = 95.82 #MOLES/HR

H_2O IN AIR = $\frac{0.0055 \text{ \#}H_2O\text{/\#DA} (16465 \text{ \#DA/HR})}{18.015 \text{ \#/\#MOLE}}$ = 5.03 #MOLES/HR

P10069

AFFILIATED ENGINEERS SE, INC.
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Made By:	Date:	Job No:
PDL	12-1-95	95094-00
Checked By:	Date:	Sheet No: 2 of

Calculations For: VOLUMETRIC ANALYSIS OF PRODUCT GAS

FROM MARKS HNDBK

CONSTITUENT	# MOLES/HR IN AIR	# MOLES/HR USED/PRODUCED	# MOLES/HR IN PROD GAS	% BY VOL DRY GAS
N_2	568.54(.78084) = 443.94	(3.66)	440.28	85.20
ARGON	(568.54)(.00934) = 5.31	0	5.31	1.03
NO_2	0	0	71.19	13.78
H_2O	5.03	95.82	100.85	
O_2	119.10	(119.10)	0	
			617.63	

DRY GAS = 516.78 # MOLES/HR

WET GAS % BY VOL

N_2 = 71.29

AR = 0.86

NO_2 = 11.53

H_2O = 16.33

PARTIAL PRESSURE $P_{H_2O} = (0.1633)(102\ \#/IN^2)$

= 16.66 PSIG.

ABSOLUTE PR. = 16.66 + 14.97 = 31.63 PSIA.

SATURATION TEMP. OF H_2O @ 31.63 PSIA = 253.37°F → DEWPOINT

P10069

AFFILIATED ENGINEERS SE, INC. 3300 SW Archer Road Gainesville, Florida 32608 (904) 376-5500 FAX (904) 375-3479	Made By: PDL	Date: 12-1-95	Job No: 95094-00
	Checked By:	Date:	Sheet No: 3 of

Calculations For: PRODUCT GAS

$$Cp_{PR.G.} = \frac{W_{N_2} Cp_{N_2} + W_{AR} Cp_{A} + W_{NO_2} Cp_{NO_2} + W_{H_2O} Cp_{H_2O}}{W_{PR.G.}}$$

$W_{N_2} = 440.28$ #MOLES/HR $(28.013) = 12333.56$ #/HR

$W_{A} = 5.31$ #MOLES/HR $(39.948) = 212.12$ #/HR

$W_{NO_2} = 71.19$ #MOLES/HR $(46.005) = 3275.12$ #/HR

$W_{H_2O} = 100.85$ #MOLES/HR$)(18.015) = \underline{1816.85}$ #/HR

17637.65 #/HR

$Cp_{N_2} = 0.227 + 0.0000292(1260) = 0.264$ B/#°F

$Cp_{A} = 4.972/39.948 = 0.124$ B/#°F

$Cp_{NO_2} = 4.972/46.006 = 0.108$ B/#°F

SEE BUFFALO TBL 6.

$Cp_{H_2O} = 0.433 + 0.0000166(1260) = 0.454$ B/#°F

$$Cp_{PR.G.} = \frac{12333.56(0.264) + 212.12(0.124) + 3275.12(0.108) + 1816.85(0.454)}{17637.65}$$

$= 0.253$ B/#°F

P10069

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Made By: PDL	Date: 12-1-95	Job No: 95094-00
Checked By:	Date:	Sheet No: 4 of ___

Calculations For: RECOVERABLE HEAT

$$Q_{REC} = W\,C_p\,(T_{IN} - T_{OUT}) = 17638(0.253)(800-400)/1000$$

$$= 1785.0 \text{ MBH}$$

ASSUME FEEDWATER ENTERING BOILER IS 300°F & 65 PSIG

$$W_{STM} = \frac{1785000 \text{ BTUH}}{\Delta h} = \frac{1785000}{1183.1 - 282} = 1980 \text{ #/HR.}$$

@ 65 PSIG.

VOLUMETRIC ANALYSIS - PRODUCT GAS/BLEACHING AIR:

CONSTITUENT	# MOLES/HR IN BLCHNG AIR	# MOLES/HR IN PR. GAS ENTG.	# MOLES/HR IN NEW PR. GAS	% BY VOL
N_2	95.96(.78084) = 74.93	440.28	515.21	72.05
A	95.96(.00934) = 0.90	5.31	6.21	0.87
O_2	95.96(.20948) = 20.10	0	20.10	2.81
NO_2	0	71.76	71.76	10.04
H_2O	$\frac{15.45}{18.013}$ = 0.86	100.85	101.75	14.23
			715.03	

BLEACHING AIR: 2779 #DA/HR + 15.45 #H_2O/HR = 2794.45
#MOLES DA/HR = 2779/28.96 = 95.96

ASSUME ALL AVAILABLE O_2 COMBINES W/ AVAILABLE N_2:

$$N_2 + 2O_2 \longrightarrow 2NO_2$$

P10069

AEI	AFFILIATED ENGINEERS SE, INC. 3300 SW Archer Road Gainesville, Florida 32608 (904) 376-5500 FAX (904) 375-3479	Made By: PDL	Date: 12-1	Job No:
		Checked By:	Date:	Sheet No: 5 of ____

Calculations For: PRODUCT & TAILGAS

CONSTITUENT	# MOLES ENT. COL	# MOLES IN PROD	# MOLES IN TAILGAS
N_2	$515.21 - \frac{20.10}{2} = 505.16$	0	505.16
A	6.21	0	6.21
O_2	0	0	0
NO_2	$71.76 + 20.10 = 91.86$	0	0
H_2O	101.75	66.39 LIQUID	4.74 VAPOR
HNO_3	$\frac{91.86(2)}{3} = 0$	61.24	0
NO	$\frac{91.86}{3} = 0$	0	30.62
		127.63	546.73

REACTION:

$$3NO_2 + H_2O \longrightarrow 2HNO_3 + NO$$

WATER IN REACTION $\rightarrow \dfrac{91.86}{3} = 30.62$ #MOLES/HR

WATER IN TAILGAS $\rightarrow \dfrac{15450\ \#/HR\,(0.0055\ \#H_2O/\#DG)}{(1.00 - 0.0055\ \#H_2O/\#DG)(18.015)} = 4.74$ #MOLES/HR

PRODUCT $\rightarrow$ 61.24 #MOLES/H (63.013 #/#MOLE) + (66.39 #MOLES/HR)(18.015 #/#MOLE)

= 5055 #/HR

% $HNO_3 = \dfrac{61.24(100)}{127.63} = 47.98$ BY VOLUME

% $HNO_3 = \dfrac{61.24(63.013)}{5055} = .7634$ BY WIEGHT

P10069

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Made By: PDL	Date: 11-9-95	Job No: 95094-00
Checked By:	Date:	Sheet No: ____ of ____

Calculations For: ABSORPTION COLUMN OUTLET FLOWS (RATED PRODUCTION)

61% DILUTE $HNO_3 = \frac{50\ TPD (2000 \#/T)}{24\ H/D (.61)} = 6830 \#/H$

HNO_3 MOL. WT. = 63.016

$HNO_3 = \frac{(0.61)(\cancel{4167}\ 6830)}{63.016} = \cancel{40.34}\ 66.11$ # MOLE/HR

$H_2O = \frac{(0.39)(\cancel{4167}\ 6830)}{18.016} = \cancel{90.20}\ 147.85$ # MOLE/HR

ASSUME TAILGAS CONTAINS WATER VAPOR QUANTITY EQUAL TO AMOUNT PRESENT IN SATURATED AIR @ 60PSIG AND 85°F.

$H_2O = 0.0055 \#/\# (15450 \#/HR) = 85 \#/HR$

$\# MOLES/HR = \frac{85}{18.016} = 4.72$

SPRAY WATER RQD = $\cancel{90.20}\ 147.85 + 4.72 - \cancel{45.15}\ 11.94 = \cancel{49.77}\ 140.63$ # MO/H

OR $\frac{\cancel{49.77}\ 140.63 \#MO/HR (18.016 \#/\#MOLE)}{8.33 \#/G (60\ M/HR)} = 5.06$ GPM
OR 2530 #/HR

TAIL GAS	# MOLES/HR	MOL. WT.	MOLES
O_2	12.11	32	0.38
N_2	435.64	28.016	15.55
NO	45.82	30.008	1.53
H_2O	4.72	18.016	0.26
	498.29		17.72

MOL. WT. = $\frac{498.29}{17.72}$ = 28.12

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	Checked By:	Date:	Sheet No: 6 of

Calculations For: PRODUCT AND TAILGAS (BY MOLAL ANALYSIS)

SPRAY WATER ADDED = 0.3 GPM (8.35 #/GAL)(60 M/HR)

= 150.3 #/HR

TOTAL PRODUCT = 5205 #/HR

ABSORPTION COLUMN MASS BALACE:

$W_{IN} = 505.16(28.014) + 6.21(39.948) + 91.86(46.01) + 101.75(18.013) + 150$

$= 20609$ #/HR

$W_{OUT} = 505.16(28.014) + 6.21(39.948) + 4.74(18.013) + 30.62(30.01) + 5205$

$= 20610$ #/HR

TAILGAS = 20610 − 5205 = 15405 #/HR

PRODUCT % HNO_3 = $\dfrac{\overset{\text{\# MOLES } HNO_3}{61.24(100)}}{\underset{\text{SPECIFIC \# MOLES}}{127.63} + \underset{H_2O \text{ \# MOLES}}{150.3/18.013}}$ = 45.04 % BY VOL

PRODUCT % HNO_3 = $\dfrac{61.24(63.013)(100)}{5205}$ = 74.14 % BY WT.

CALCULATE ADDITIONAL SPRAYWATER REQUIRED TO PRODUCE 61% HNO_3 BY WIEGHT:

$.61(5205 + w) = 61.24(63.013)$

$w = 1121.1$ #/HR

TOTAL PRODUCT = 5205 + 1121

= 6326 #/HR

SPRAY WATER = $\dfrac{(1121.1 + 150.3)}{8.35(60)}$ = 2.5 GPM

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Made By:	Date:	Job No:
PDL	11-9-95	95094-00
Checked By:	Date:	Sheet No: ____ of ____

Calculations For: ENERGY INVENTORY AT AIR PREHEATER

EXISTING SYSTEM

HEAT LOSS FROM BARE PIPE:

REF. SCHULLER HEAT TRANSFER TABLES
18"ϕ @ 1200°F PIPE OPER. TEMP. - BARE - DULL

$$Q = \frac{54455 \text{ BTUH/FT} (15 \text{ FT})}{1000} = 980.2 \text{ MBH}$$

HEAT TRANSFERRED TO AIR:

$$Q = W C_p \Delta T = \frac{16556}{1000}(0.24)(625-100)$$

$$= 2086.1 \text{ MBH}$$

HEAT REMOVED FROM PRODUCT GAS:

$$Q = 980.2 + 2086.1 = 3066.3 \text{ MBH}$$

HEAT TRANSFERRED TO WATER @ CONVERTER:

$$Q = \frac{500}{1000}(GPM)(\Delta T) = \frac{500}{1000}(77)(140-65)$$

$$= 2887.5 \text{ MBH}$$

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Made By: PDL	Date: 11-12-95	Job No: 95094-00
Checked By:	Date:	Sheet No: ____ of ____

Calculations For: COOLING WATER AT CASCADE COOLER

EXISTING SYSTEM

Q = (LBS EVAP/HR)(950) + (~~16020~~ 15445 − LBS EVAP)(100° − 75°)

LBS EVAP/HR = W

~~3413.7~~ 4018.7 (1000) = 950 W + ~~10250~~ 15445 (25) − 25 W

$$W = \frac{\cancel{3413}\ 4018\ 700 - \cancel{256250}\ 386125}{925} = \cancel{3665}\ 3927 \ \#/HR$$

DRAIN = 15445 − 3927 = 11520 #/HR

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Made By: PDL	Date: 11-9-95	Job No: 95094-00
Checked By:	Date:	Sheet No: ____ of ____

Calculations For: ENERGY INVENTORY AT ABSORPTION COLUMNS

EXISTING SYSTEM

ADDITIONAL WATER CONDENSED:

$$H_2O = (0.0065\ \#H_2O/\#\text{DRY GAS})(19900\ \#DG/HR) - 85\ \#/H$$

$$= 44.35\ \#/HR$$

$$\text{HEAT REMOVED} = \frac{44.35(h_{fg})}{1000} = \frac{44.35(873)}{1000} = 38.7\ \text{MBH}$$

APPROX. HEAT REMOVED FROM GAS:

$$Q = W C_p \Delta T = \frac{15450}{1000}(0.25)(105-85)$$

$$= 115.9\ \text{MBH}$$

FROM TECHNICAL REPORT NO. HDC-39-77, APPARENT ACID CHEMICAL HEAT LEAVING THE COLUMN IS 112.5 MBH (SEE REFERENCE MATERIAL IN APPENDIX)

RQ.D. COOLING WATER:

$$\text{CH WTR. GPM} = \frac{(38.7 + 115.9)}{(2)500(45-35)} = 15.5 \text{ OR } 7750\ \#/HR$$

$$\text{CW GPM} = \frac{38.7 + 115.9}{500(65-75)} = 30.9 \text{ OR } 15445\ \#/HR$$

P10069

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	Checked By:	Date:	Sheet No: ______ of ______

Calculations For: WATER CHILLER

ASSUME HEAT REJECTED IN EXTENDED ABSORPTION COLUMN IS ONE HALF THE TOTAL FOR BOTH COLUMNS.

ASSUME CHILLER STEAM REQUIREMENTS ARE 22.5 #/HR STEAM PER TON OF REFRIG.

$$\text{TONS} = \frac{(115.9 + 38.7)\,\text{MBH}}{(2)\ 12.000\ \text{MBH/TON}} = 6.44\ \text{TONS}$$

$$\text{STEAM} = 6.44 \times 22.5 = 145\ \#/\text{HR}$$

BAROMETRIC CONDENSER:

$$\text{HEAT GAIN} = 145\,(h_{fg}) = 145\,(1045.8)$$ *ASSUME 85° COND. TEMP.

$$= 151640\ \text{BTUH}$$

FOR ΔT OF 20°F:

$$\text{GPM} = \frac{151640}{500\ (20)} = 15\ \text{OR}\ 7580\ \#/\text{HR}$$

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PDL	12-5-95	95094-00
Checked By:	**Date:**	**Sheet No:**
		7 of

Calculations For: TAILGAS (BY MOLAL ANALYSIS)

$$Cp_{TG} = \frac{W_{N_2} Cp_{N_2} + W_{AR} Cp_{AR} + W_{NO} Cp_{NO} + W_{H_2O} Cp_{H_2O}}{W_{TG}}$$

$W_{N_2} = 505.16(28.013) = 14151.05$

$W_{AR} = 6.21(39.948) = 248.08$

$W_{NO} = 30.62(30.01) = 918.91$

$W_{H_2O} = 4.74(18.015) = \underline{85.39}$

15403.43

CALCULATE Cp @ 350°F (810°R)

$Cp_{N_2} = 0.227 + 0.0000292(810) = 0.251$

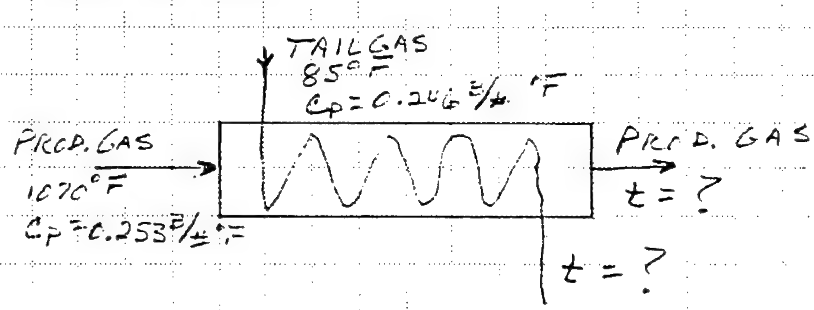
$Cp_{AR} = 4.972/39.948 = 0.124$

$Cp_{NO} = 4.972/30.01 = 0.177$

$Cp_{H_2O} = 0.433 + 0.0000166(810) = 0.446$

$$Cp_{TG} = \frac{14151.05(.251) + 248.08(0.124) + 918.91(0.177) + 85.39(0.446)}{15403.43}$$

$= 0.246$ B/#°F



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Made By: PDL	Date: 12-5-95	Job No: 95094-00
Checked By:	Date:	Sheet No: 8 of

Calculations For: TAILGAS HEATER

CALCULATE HEATER "EFFECTIVNES" USING EXISTING SYSTEM PARAMETERS:

$$EFF = \frac{T_{T.G.OUT} - T_{T.G.IN}}{T_{P.G.IN} - T_{T.G.IN}} = \frac{785-85}{1070-85} = 0.711$$

USING CALCULATED EFF, DETERMINE PROCESS PARAMETERS OF THE INSULATED SYSTEM:

$$T_{T.G.OUT} = T_{T.G.IN} + 0.711(T_{P.G.IN} - T_{T.G.IN}) = 85 + 0.711(1205-85)$$

$$= 881°F$$

$$Q_{RECOV.} = W_{TG}\, C_{P_{TG}}(T_{TG\,OUT} - T_{TG\,IN}) = 15403.43(0.246)(881-85)$$

$$= 3,017,450 \text{ BTUH}$$

$$T_{P.G.OUT} = T_{P.G.IN} - \frac{Q_{RECOV.}}{W_{P.G.}\, C_{P_{P.G.}}} = 1205 - \frac{3017450}{17637.65(0.253)}$$

$$= 529°F$$

$$Q_{EXIST'G} = W_{T.G.}\, C_{P_{T.G.}}(T_{T.G.OUT} - T_{T.G.IN}) = 15403.43(435-85)(0.246)$$

$$= 1,326,235 \text{ BTUH}$$

$$\Delta Q = 3017450 - 1326235 = 1691215 \text{ BTUH}$$

* ABOVE ΔQ SHOULD BE APPROXIMATELY EQUAL TO THE REDUCTION IN PIPE LOSS TO ATMOS. BY ADDING INSUL.

$$Q_{INSUL.SVGS.} = 980200 - 41900 + 554300 - 34900 = 1,457,700 \text{ BTUH}$$

$$\% \text{ ERROR} = \frac{1691215 - 1457700}{1691215}(100) = 13.8\%$$

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Made By:	Date:	Job No:
PDL	12-5-95	95094-00
Checked By:	Date:	Sheet No: 9 of ____

Calculations For: TAILGAS PIPING

CALCULATE TAILGAS VELOCITY IN PIPING TO TURBINE:

MTL. – 6" HCI – USE ASTM A312 GRADE TP321

SCH. No. = 1000 P/SE

P = 90 PSIG @ 800°F

SE = 12850 PSI

$$\text{SCH. No} = \frac{1000(90)}{12850} = 7$$

USE SCHEDULE 10S → ID = 6.357 IN

AREA = 31.7 IN²

$$\frac{P_1 v_1}{R T_1} = \frac{P_2 v_2}{R T_2}$$

STANDARD ATMOSPHERE: 518.7°R, 14.696 PSIA, 0.07651 #/FT³

$$v_2 = \frac{14.696(1/0.07651)(1260°R)}{518.7\ (90+14.696)} = 4.457\ FT^3/\#$$

$$V = \frac{15403.43\ \#/HR\ (4.457\ FT^3/\#)}{60\ M/HR\ (31.7\ IN^2/144\ IN^2/FT^2)} = 5197\ FPM$$

PIPE DEVELOPED LENGTH = 75 FT.

USE EQUIVALENT LENGTH = 75(1.33) = 100 FT

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Made By: PDL	Date: 12-5-95	Job No: 95094-00
Checked By:	Date:	Sheet No: 10 of ____

Calculations For: TAILGAS PIPING

$$N_{RE} = \frac{VD\rho}{\mu} = \frac{5197\ FT/MIN\ (6.357\ IN)(60\ MIN/HR)}{12\ IN/FT\ (4.457\ FT^3/\#)(0.081\ \#/FT\text{-}HR)}$$

$$= 457,559$$

$$\Delta P = \frac{3.4\times10^{-6} f L W^2 v}{d^5} = \frac{3.4\times10^{-6}(0.008)(100)(15403.43)^2}{(6.357)^5\ (1/4.457)}$$

$$= 0.28\ PSI$$

ASSUMING TAILGAS PRESSURE LEAVING TAILGAS HEATER IS 60 PSIG, CALCULATE STEAM PRODUCTION CAPABILITY OF HEAT RECOVERY BOILER ASSUMING PRODUCT GAS TEMPERATURE LEAVING THE BOILER OF 400°F, FEEDWATER ECONOMIZER OUTLET (BOILER INLET) TEMPERATURE OF 300°F, AND 50°F SUPERHEAT.

$$W_{STM} = \frac{W_{P.G.}\ C_{P_{PG}}\ (T_{PG,IN} - T_{PG,OUT})}{(h_{STM\ OUT} - h_{FW\ IN})} = \frac{17637.65(0.253)(529-400)}{(1210.0 - 280)}$$

$$= 619\ \#/HR\ @\ 360°F\ \&\ 78\ PSIA$$

$$W_{WET\ GAS} = W_{T.G.} + W_{STM} = 15403.43 + 619 = 16022\ \#/HR$$

$v_{STM} = 6.045\ FT^3/\#$ FROM KEENAN & KEYES

$$v_{WET\ GAS} = \frac{6.045(619) + 4.457(15403.43)}{16022} = 4.518\ FT^3/\#$$

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Made By:	Date:	Job No:
Checked By:	Date:	Sheet No: ____ of ____

Calculations For: TABLE 1

AMMONIA VAPORIZOR:

$Q_{GAIN_{STM}} = 694$ #/HR $(1273$ B/# $- 244$ B/#$) = 714\ 126$ BTUH

$Q_{LOSS_{COND.}} = 694$ #/HR $(1$ B/#°F$)(275° - 60°) = 149210$ BTUH

MIXER:

$Q_{TRANS(AIR)} = 16556$ #/HR $(0.24$ B/#°F$)(625 - 580°) = 178\ 804$ BTUH

$Q_{TRANSF(NH_3)} = 1080$ #/HR $(0.54$ B/#F$)(580° - 275°) = 177{,}876$ BTUH

CONVERTOR:

CLNG. WTR: $Q_{REJ.} = 38499$ #/HR $(1$ B/#°F$)(140 - 65) = 2{,}887{,}425$ BTUH

$Q_{REACTION} = 7136.1$ BTUH - SEE NEXT SHEET

AIR PREHEATER:

$Q_{REJ.(AIR)} = 16556$ #/HR $(0.24$ B/#°F$)(625 - 100) = 2{,}086{,}056$ BTUH

REF. SCHULLER HT. TRANSF. TABLE

$Q_{REJ(ATMOS)} = 54455$ BTUH/FT $(15$ FT$) = 816825$ BTUH

$T_{PG\ OUT} = T_{PG,IN} - \frac{Q_{REJAIR} + Q_{REJATM}}{w_{PG}\, C_{P_{PG}}} = 1470 - \frac{2086056 + 816825}{17644(0.253)} = 819.7$

TAILGAS HEATER:

$T_{TG\ OUT} = T_{TG\ IN} + EFF(T_{PG\ IN} - T_{TG,IN}) = 85 + 0.711(819.7 - 85) = 607.4°F$

$Q_{TG} = W C_P \Delta T = 15450(0.248)(607.4 - 85) = 2001528$ BTUH

$Q_{REJ\ ATMOS} = 9997(21) = 209937$

$T_{PG\ OUT} = T_{PG\ IN} - \frac{(Q_{TG} + Q_{REJAT})}{W_{PG} C_{P_{PG}}} = 819.7 - \frac{(2001528 + 209937)}{17644(0.253)} = 324.3$

CASCADE COOLER:

$Q_{REJ_{GAS}} = W_{DG} C_P \Delta T = 17092(0.253$ B/#°F$)(607.4 - 105)$

$= 2{,}172{,}516$ BTUH

$Q_{REJ_{CONDENS}} = 673{,}700$ BTUH - SEE NEXT PAGE

$Q_{REACT} = 0.80(6086.7) = 4{,}869{,}400$ BTUH

P10069

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	Checked By:	Date:	Sheet No: ____ of ____

Calculations For: REACTION HEAT TABLE 1

$$4NH_3 + 7O_2 \rightarrow 4NO_2 + 6H_2O$$

CONSTITUENT	HEAT OF COMBUSTION	CONSTITUENT LBS/HR	SYSTEM NET HEAT
NH_3	1163 B/#	1088	(1,265,344 BTUH)
O_2	–	–	–
NO_2	(1443.7 B/#) 33.1×10³ J/MOL (9.48×10⁻⁴ B/J)	2939 1287	(4,242,963 BTUH) (1,858,042 BTUH)
H_2O	6827 B/# (LIQUID) $h_g - h_f = 1856.0 - 313.8 = 1542.2$	1726.2	11,784,767 BTUH 2,717,665 BTUH

NET = 7,136,082 BTUH

$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$$

CONSTITUENT	HEAT OF COMBUSTION	CONSTITUENT LBS/HR	SYSTEM NET HEAT
NO_2	(1443.7 B/#)	4226	6,101,076
H_2O	6827 B/# (LIQUID) $h_g - h_f = 1530.3 - 309.8 = 1220.5$	552	(3768504 BTUH) (673716 BTUH)
HNO_3	1190 B/# (LIQUID) $h_g - h_f = 206$ B/#	4025	4,789,750 BTUH 829150
NO	(1296 B/#)	919	(1,191,024 BTUH)

NET 6,086,732

P10069

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Made By:	Date:	Job No:
Checked By:	Date:	Sheet No: ____ of ____

Calculations For: TABLE 1

PRODUCT

SOLUTION – 198.2 # MOLES/HR

HNO_3 – 61.2 # MOLES/HR

REFERENCE "HEAT OF DILUTION OF ACIDS" TABLE

$$n = \frac{198.2 - 61.2}{61.2} = 2.2$$

$$\Phi_L = 2952 \text{ cal/mol} = 12351.168 \text{ Joules/mol}$$

$$\text{HEAT OF DILUTION} = 12351.168 \text{ Joules/mol } (61.2 \text{ \# moles/HR})(9.48 \times 10^{-4} \text{ B/Joule})$$

$$= 716 \text{ BTUH}$$

HEAT ABOVE AMBIENT:

$$Q = WC_p\Delta T = 6830 \text{ \#/HR}(0.64 \text{ B/\#°F})(87-60)$$

$$= 118022 \text{ BTUH}$$

ABSORPTION COLUMNS:

$$Q_{REJ_{GAS}} = W_{DG} C_p \Delta T = 17092(0.253)(105-85)$$

$$= 86{,}485 \text{ BTUH}$$

$Q_{REJ_{CONDENS}} = 0 \rightarrow$ ALL CONDENSATION IN PRODUCT GAS OCCURS IN CASCADE COOLER CALCS.

$Q_{REAT.} = 0.2(6086.7) = 1217{,}300 \text{ BTUH}$

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Made By:	Date:	Job No:
Checked By:	Date:	Sheet No: ____ of ____

Calculations For: TABLE 1

TURBINE:

FROM KEENAN & KAYE @ 324°F (784°R): $P_{r_1} = 5.144$, $h_1 = 187.92$

$$P_{r_2} = P_{R_1}\left(\frac{P_2}{P_1}\right) = 5.144\left(\frac{15}{73}\right) = 1.057$$

$$h_{2THEOR} = 119.4$$

$$h_2 = h_1 - E_{TURB}(h_1 - h_{2THEOR}) = 187.92 - 0.725(187.92 - 119.4)$$

$$= 138.2 \text{ B/\#}$$

$$T_2 = 578°R \text{ OR } 118°F$$

$$WK_{TURB} = \frac{W_{TG}\,\Delta h}{2545} = \frac{15450(187.92 - 138.2)}{2545} = 301.8 \text{ HP}$$

$$Q_{TURB} = 301.8(2545) = 768174 \text{ BTUH}$$

$$Q_{REJATM} = W\,C_P\,\Delta T = 15450(0.248)(118-60) = 222233 \text{ BTUH}$$

$$Q_{REJEXH} = W\,C_P\,\Delta T = 15450(0.248)(607.4-60) = 2097418$$

AIR COMPRESSOR:

FROM JOY MFR. CO. TEST PERFORMANCE CURVE EXTRAPOLATED TO 4195 SCFM DELIVERY — USE 1095 HP

$$Q_{MTR} = \frac{(1095-302)(2545)}{1000} = 2018.2 \text{ MBH}$$

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Made By: PDL	Date: 11-12-95	Job No: 95095
Checked By:	Date:	Sheet No: ____ of ____

Calculations For: TURBINE DRIVE FOR AIR COMPRESSOR ECO #1

USING FIG. 4 (ATTACHED) FROM MARK'S HANDBOOK:

$$\text{RATIO OF COMPR} = \frac{(115+14.7)^{1/2}}{14.7} = 2.974$$

$$HP = \frac{69(4197\,SCFM)(1440)(1.03)(2)}{10^6} = 859$$

~~$HP = \frac{859}{.748} = 1152$~~

FROM MOLLIER DIAGRAM:

$$\Delta h = 1271\ B/\# - \cancel{1042}\ 1054\ B/\# = \cancel{229}\ 217\ B/\#$$

STEAM RQD. @ 75% TURB. EFF:

$$W = \frac{859\ HP(2545\ B/HP\text{-}H)}{\cancel{229}\ 217(.75)} = \cancel{12730}\ 13432\ \#/HR$$

RIVER WATER FOR CONDENSER:

COND. TEMP = 101°F @ 2" H_G

FOR 95% QUALITY STEAM:

$$h_{6\%} = h_f + x(h_g - h_f) = 69.1 + .95(1036.6)$$

$$= 1053.9$$

$$Q_{COND} = \frac{\cancel{12730}\ 13432(1053.9 - 69.1)}{1000} = \cancel{12536}\ 13228\ MBH$$

$$\text{RIV. WTR} = \frac{Q_{COND}}{500(\Delta T)} = \frac{\cancel{12536}\ 13228 \times 1000}{500(95-65)} = \cancel{835}\ 880\ GPM$$

P10069

$$\Sigma_{dng} = 227[(1.08R_c)^{0.203} - 1] \tag{4}$$

) $\Sigma_{dnu} = 0.0456\ \overline{m}c_v\ \Delta t$, where c_v is the specific heat at tant volume and Δt is the isentropic temperature rise. A tiplier of 0.147 applied to the above Σ values gives the bhp 100 ft³/min at 14.4 psia and 60°F. Figure 4 illustrates a ular empirical solution for Σ, wherein an arbitrary pre[illegible] efficiency of 68 percent is applied at $1.5R_c$, 78 ent [illegible] R_c, and 87 percent at $4R_c$. Mechanical efficiency of ercent is widely accepted, which includes loss allowances percent for piston-ring friction and piston-rod packing 3 percent for gearing friction of the crosshead, slipper es, connecting-rod pins, and crankshaft bearings. The r losses are dissipated by convectional air circulation in ie sizes under 300 hp and into the lubricant system in er sizes. The ring and packing losses are mostly absorbed he jacket-water system. Where the cylinder power is less 100 hp, these losses should be doubled.

perature Rise

on compression is essentially an adiabatic function, espe- when referred to the internal cylinder conditions. The pression-temperature rise follows the equation

$$T_2 = T_1(KR_c)^{\sigma/\eta} \tag{5}$$

re η represents the heat leak factor applied in a manner istent with the thermal efficiency. These factors are less 1.05 for normal water-jacket cylinders, 1.09 for dry- et cylinders, 1.11 for forced-air-cooled cylinders with fins, 1.15 for high-velocity water-jacket cooling and the expan- cycle, curve *CFD* on Fig. 1. There was a time when water injected into the suction of air compressors to reduce the harge temperature; when the speed of machinery was ased and the clearance volume reduced, the practice was dor[illegible] s hazardous. The temperature drop was substan- η [illegible] 1.75. The scheme is still applied in chemical esses to wash out unsaturated gums and to suppress the harge temperature of exothermic gases. The liquid is ly a light solvent of the same character as the gas and is ized into the suction line. A short, 10-s blast of steam 2 or 4 h can usually clear the gums from a cylinder. ie temperature behavior is only consistent below $4R_c$; nd this, the cylinder cooling effect is perceptible because e reduced mass flow at higher R_c operation. European ice of process sizing includes a **warm-up** factor, which mes the gas is heated 20 to 40°F in passing through the ylinder and suction valves. Such a correction comple- the volumetric efficiency by a judgment factor of 0.95 0. Thermocouple probes in the suction valve and in the stream show no such evidence at the ambient-tempera- range. American practice has always disregarded such ctions. The warm-up factor also allows for valve and 1-ring leakage. If such leakage is perceptible, the temper- rise is usually cumulative and readily detectable by iometry.

ression Efficiency

oression efficiency is an approximate method of account- or all the power losses that occur between stagnant on and discharge pressures. It presumes that all valve an[illegible]s channels offer equal resistance and that the res[illegible] eed and character of the gas are inconsequential.

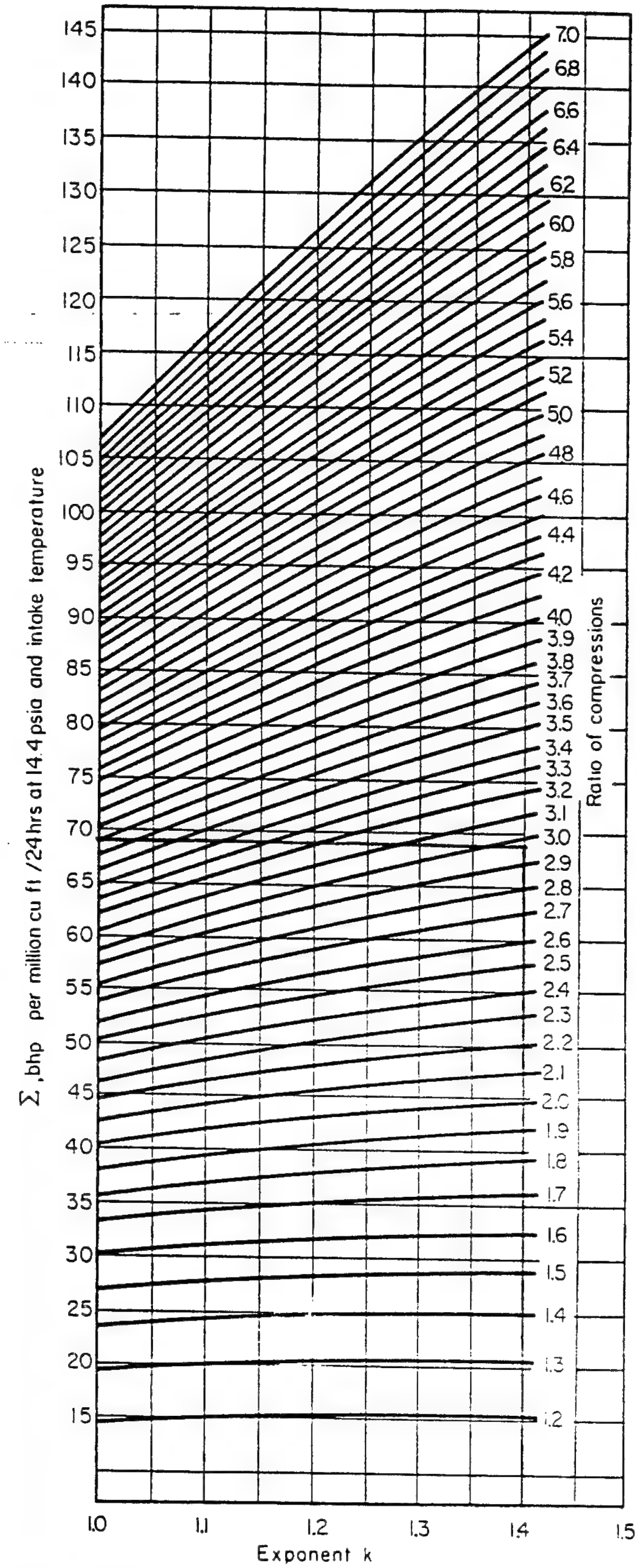


Fig. 4 Approximate horsepower to compress air or gas. If single-stage, multiply cubic feet actual capacity of free gas per minute by 1,440 to obtain capacity in millions of cubic feet per 24 h. Then capacity in 24 h times horsepower per million as obtained from the chart will give the total horsepower. If two-stage, take the square root of the total number of compressions. Read the horsepower from the chart for this ratio, multiplying the same for the two stages, to which add 3 percent for cooler loss. Note that horsepower is for 14.4 psia intake. If horse-power based on capacity at 14.7 psia, add 2 percent to horsepower.

HP = 69

ECO No. 1

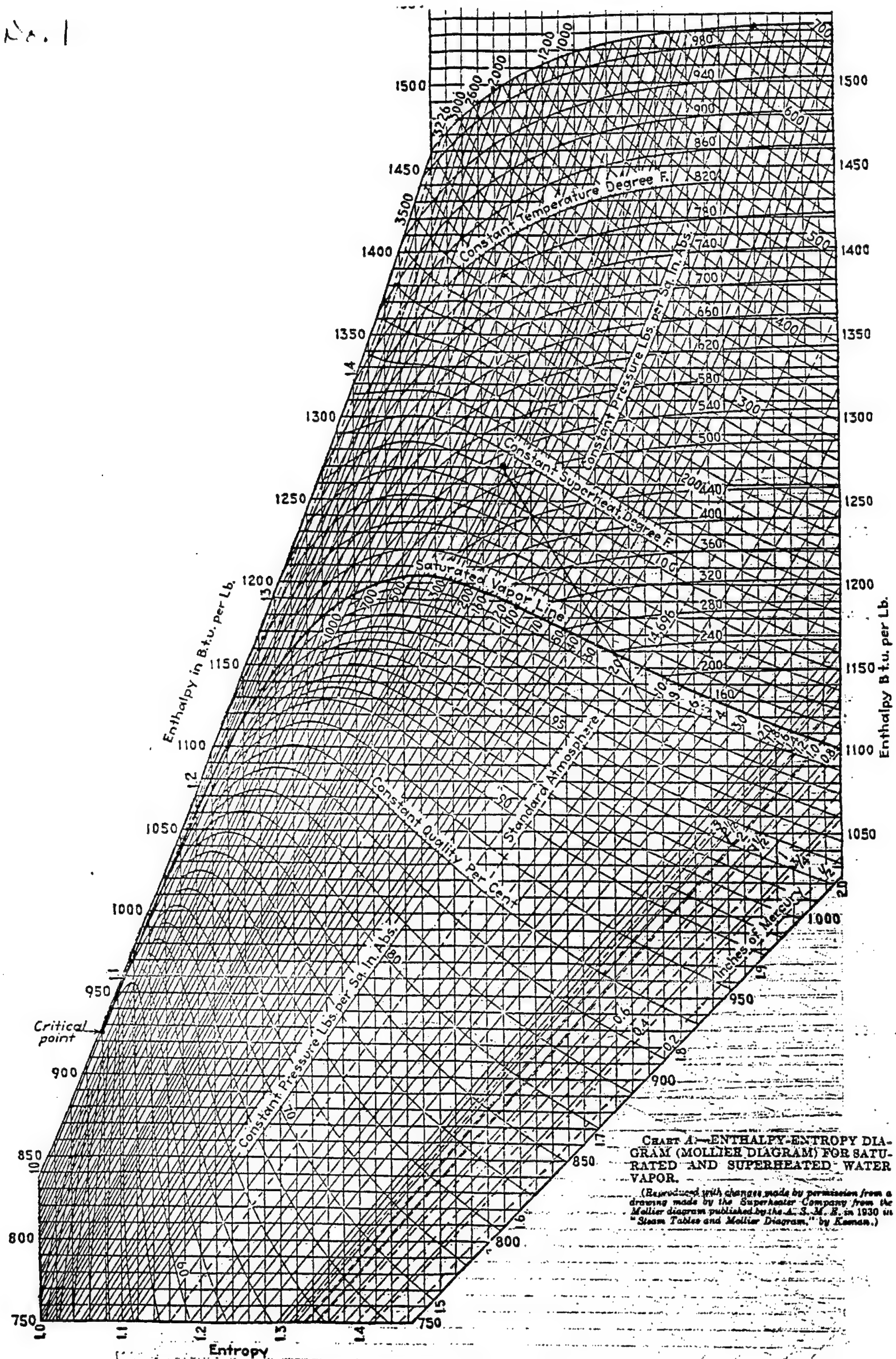


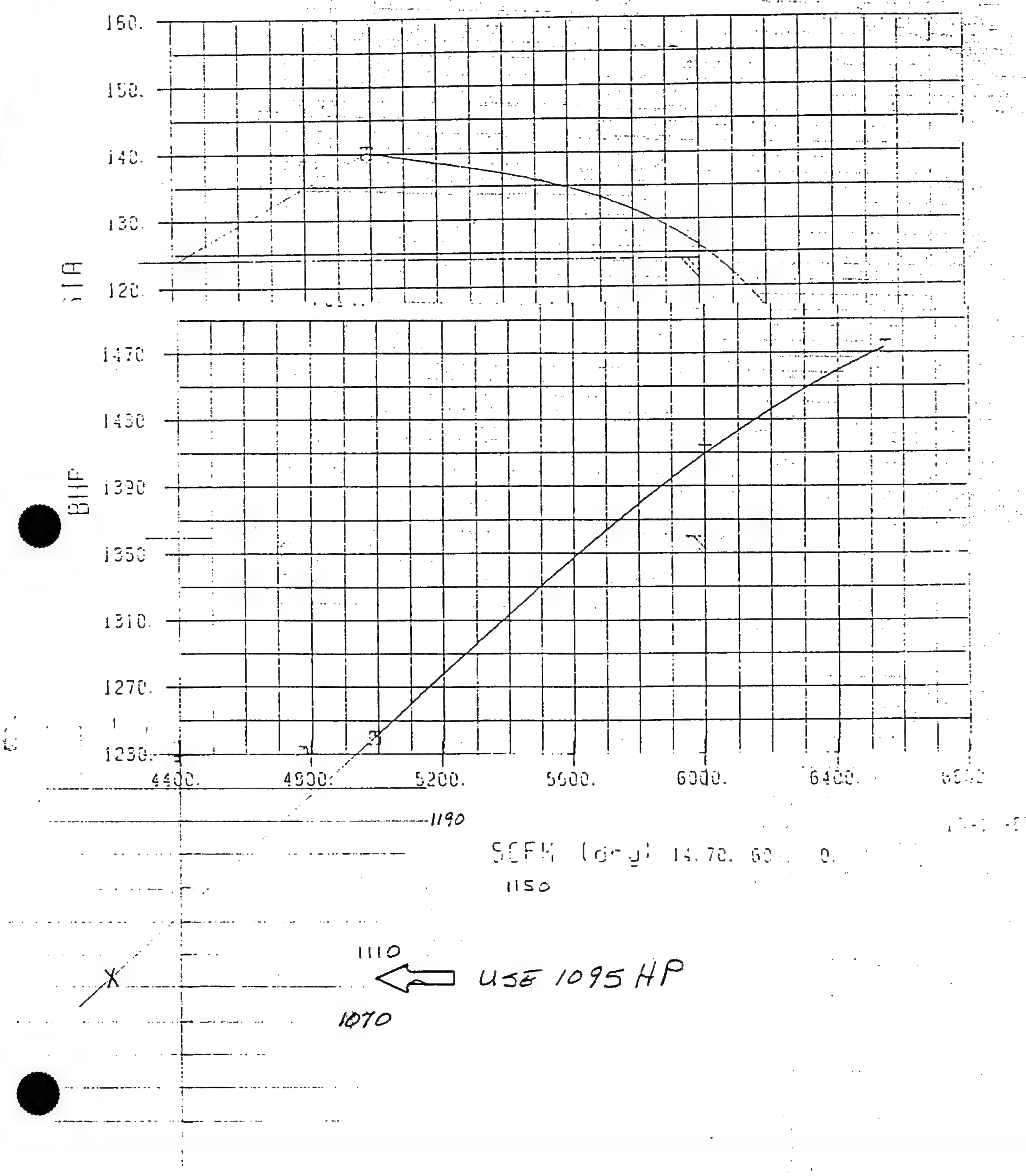
CHART A.—ENTHALPY-ENTROPY DIAGRAM (MOLLIER DIAGRAM) FOR SATURATED AND SUPERHEATED WATER VAPOR.

(Reproduced with changes made by permission from a drawing made by the Superheater Company from the Mollier diagram published by the A. S. M. E. in 1930 in "Steam Tables and Mollier Diagram," by Keenan.)

JOY MANUFACTURING CO. BUFFALO N.Y.

TEST PERFORMANCE F07693M1 CUSTOMER WITNESS TEST

7693 HOLSTEN DEFENSE CORP 1970SZ



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Calculations For: ECO No. 1

INACTIVE HEATER LOSS TO ATMOS:

$$Q = \frac{21\,FT\,(33526\ ^{BTUH}/FT)}{1000} = 704.0\ MBH$$

$$Q = W\,C_p\,\Delta T$$

APPARENT PRODUCT GAS Cp FROM EXISTG. SYST. CALCS:

$$Q_{EX.} = 1895{,}400 = 17644\,(C_{P_{EX}})(1070 - 785)$$

$$C_{P_{EX}} = 0.377\ B/\#\,°F$$

$$704000 = 17644\,(0.377)(1070 - T_{LVG})$$

$$T_{LVG} = 1070 - \frac{704000}{17644(0.377)} = 964°F$$

CASCADE COOLER DRAIN:

$$Q = (\#/HR\,EV)\,h_{fg} + (15445\ \#/HR - \#/HR\,EV)\,\Delta T$$

$$Q = W\,C_p\,\Delta T = \frac{17644}{1000}(0.377)(965 - 105)$$

$$= 5720.5\ MBH$$

$$\#/HR\ EVAP = \frac{5720500\ B/HR - (15445\ \#/H)(100° - 75°)}{950 - 25}$$

$$= 5767\ \#/HR$$

DRAIN = 15445 − 5767 = 9678 #/H OR 19 GPM

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Calculations For: ECO No. 1

TAILGAS RELEASE TO ATMOSPH.

$Q = W C_p \Delta T = 15450(0.248)(85-60)/1000$

$= 95.8$ MBH

ELECT ENERGY SAVINGS

$\frac{1359.1 \text{ MBH}(1152 \text{ H/YR})}{1000} = 1580$ MILLION BTU/YR

ADDITIONAL STEAM RQD. $= \frac{13432 \text{ \#/HR}(1285 - 1105.7) \text{ B/\#}\ (1152 \text{ H/YR})}{1000000}$

$= 2774$ MILLION BTU/YR

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Calculations For: TABLE 2

AMMONIA VAPORIZER, MIXER, CONVERTOR AND AIR PREHEATER CONDITIONS IDENTICAL TO TABLE 1 CALCS.

TAILGAS HEATER:

REF. SCHULLER HT. TRNSF. TABLE

$Q_{REJ_{1000°}} = 33526\,(21) = 704046$ BTUH

$$\Delta T_{PG} = \frac{704046}{17644\,(0.253)} = 157.7°$$

$$T_{LUG} = 1070 - 157.7 = 912°F$$

CASCADE COOLER:

$Q_{REJ_{GAS}} = W_{DG}\, C_P\, \Delta T = 17092\,(0.253)(912-105) = 3{,}489{,}691$ BTUH

$Q_{REJ_{CONDENS}} = 673700$ BTUH – SAME AS TABLE 1

$Q_{REACT} = 4869400$ BTUH – " " "

ABSORPTION COLUMNS:

SAME AS TABLE 1

STEAM TURBINE:

$Q_{GAIN} = 1095\text{ HP}(2545\,^{B}/_{HP}) = 2{,}786{,}775$ BTUH

$$W_{STM} = \frac{Q_{GAIN}}{\Delta h_{STM}} = \frac{2786775}{1271-1054} = 12{,}842\ \#/HR$$

$Q_{REJ} = W_{STM}\,\Delta h_{STM} = 12842(1105.7-69.1) = 13{,}312{,}017$ BTUH

$Q_{REJ_{COND}} = 12842(1)(110-60) = 526.5$

$Q_{REC} = W_{CON}\, C_{P_{CON}}\, \Delta T = 12842(1)(101-60) = 526522$ BTUH

$Q_{LOST} = 13312.0 - 526.5 = 12785.5$

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Calculations For:
TABLE 2

PRODUCT: SAME AS TABLE 1

STACK LOSS:

$$Q_{REJ} = W\, C_p\, \Delta T = 15450(0.248)(85-60)$$

$$= 95790 \text{ BTUH}$$

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Calculations For: ECO No. 2			

HEAT LOSS FROM BARE PIPE:

18"ϕ PIPE @ 735°F OPER. TEMP. DULL:

$$Q = \left[(19265 - 9997)\frac{(135)}{200} + 9997\right]\frac{21\,FT}{1000} = 341.3$$

HEAT TRANSFERRED TO DOWTHERM:

FROM EXISTING SYSTEM CALCS:

$Q_{TAILGAS} = 1341.1$ MBH

APPARENT PROD. GAS SPECIFIC HEAT:

$$C_p = \frac{134100}{(7644\,\#/HR)(1070 - 755)} = 0.267\ B/\#°F$$

$$Q_{DOWSH} = \frac{17644\,\#/HR\,(0.267\,B/\#°F)(1070 - 400)}{1000}$$

$= 3156.3$ MBH

TAILGAS EXHAUST TO ATMOSPHERE

$$Q = W C_p \Delta T = \frac{15450}{1000}(0.248)(85 - 65)$$

$= 76.6$ MBH

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Calculations For: ECO No. 2

DOWTHERM PARAMETERS:

PUMP SUCTION TEMP = $\frac{\text{STM TEMP} + \text{PR. GAS LVG. TEMP}}{2}$

$= \frac{338 + 400}{2} = 369°F$

USE 725°F ENTERING BOILER

$Q = W C_p \Delta T$ REF. TECHNICAL DATA REF. FROM TRANTER CATALOG.

$W = \frac{3156300 \text{ BTUH}}{(0.55 \text{ BTU}/\# \cdot °F)(725° - 369)} = 16120 \#/HR$

$GPM = \frac{16120 \#/HR (7.48 \text{ G}/FT^3)}{50 \#/FT^3 (60 \text{ M}/HR)} = 40 \text{ GPM}$

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Calculations For: TABLE 3

AMMONIA VAPORIZER, MIXER, CONVERTER AND AIR PREHEATER: SAME AS TABLE 1

DOWTHERM HEATER: (PROD. GAS COOLED TO 400°F - SEE SCOPE)

$Q_{REJ} = W\,C_P\,\Delta T = 17644(0.253)(1070-400) = 2{,}990{,}834$ BTUH

REF SCHULLER HT. TRNSF. TABLE

$Q_{LOSS_{735}} = \left[(19265-9997)\left(\frac{135}{200}\right)+9997\right](15\text{ FT}) = 243{,}794$ BTUH

CASCADE COOLER:

$Q_{REJ_{GAS}} = W_{PG}\,C_P\Delta T = 17092(0.253)(400-105) = 1{,}275{,}661$

$Q_{REJ_{CONDENS}} =$ SAME AS TABLE 1 = 673700 BTUH

ABSORPTION COLUMNS: SAME AS TABLE 1

AIR COMPR:

$Q_{GN} = 859(2545) = 2186300$

$Q_{REJ} =$ SAME AS TABLE 1

FINAL BLCHR: " " "

STACK LOSS:

$Q_{REJ} = W\,C_P\Delta T = 15450(0.248)(85-60) = 95790$ BTUH

STEAM: $W = \frac{Q_{REC}}{\Delta h} = \frac{2747{,}000}{(1189-168)} = 2690$ #/HR

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Calculations For: FILTERED WATER COST - ECO 3

UNIT COST OF FILTERED WATER FROM STEAM COST CALC'S BY J. BOUCHILLON IN MARCH, 1995:

\$148 PER MILLION GALLONS.
(SEE APPENDIX REFERENCE MATERIAL)

PRESENT ANNUAL CONSUMPTION = $540 \, GAL/M (60 \, M/HR)(1152 \, HR/YR)$

$= 37,324,800 \, GAL/YR$

ANNUAL COST = $\dfrac{\$148.00(37324800)}{1000000} = \$5524/YR.$

WATER SAVED = 540 GPM − 5.7 − 11.5 = 522.8 GPM

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Calculations For: ECO No. 3

EQUIPT	CLNG. WATER FLOW	LWT
CONVERTER	77 GPM	140°F
CASCADE CLR	24 GPM	100°F
AIR COMPR.	156 GPM	104°F
	109 GPM	104°F
	174 GPM	101°F

540 GPM @ MIXED TEMP = 108°F

AIR COMPR. BALANCED FOR 85°F EWT

CONVERTER SHOULD BE OKAY w/ 160°F LWT

CONSIDER INCREASING FLOW @ ABSORPTION TOWERS FOR 4° ΔT RATHER THAN 10° ΔT.

$$GPM = \frac{115900 \text{ BTUH}}{500(4)} = 58 \text{ GPM} - 28988 \text{ \#/HR}$$

CASCADE CLR DRAIN:

$$Q = W(950) + ((58)(8.33)(60) - W)(100 - 89)$$

$$W = 3940 \text{ \#/HR}$$

$$DRAIN = 58(8.33)(60) - 3940 \text{ \#/HR} = 25050 \text{ \#/HR}$$

OR 50 GPM @ 100°F

TOWER FLOW = 77 + 50 + 156 + 109 + 174 = 566 GPM

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Checked By:	Date:	Sheet No: ____ of ____

Calculations For: ECO No. 3

TOWER SELECTION:

566 GPM
108°F EWT
85°F LWT
76°F W.B.

MARLEY NC 3011

± 85000 CFM
15 HP FAN

1% BLOWDOWN – 5.7 GPM

2% MAKEUP – 11.5 GPM

ASSUME FAN OPERATES 80% OF THE TIME:

$$\text{ANNUAL FAN ENERGY} = \frac{15\ HP(0.8)(1152\ H/YR)}{0.748\ HP/KW} = 18481\ KWH/YR$$

ASSUME PUMPING ENERGY FOR THE COOLING TOWER SYSTEM OFFSETS THE SAVINGS IN PUMPING ENERGY AT PUMP HOUSE.

P10069

J. Bouchillon, PE
3/95
Rec'd [illegible] 4/6/95

1994 OUT-OF-POCKET COST FOR STEAM, B-200

GIVEN: 1994 AREA B MONTHLY USAGE & PROD. REPORT, by KEN HARRIS

Sum of individual boiler's steam output = 1,324,620,000 lbs

Building Steam Output = Sum − internal consumption (turbines, DA, etc)

16.4% (EEAP study, EMC Engineers 1992, p. C-4)

= 1,324,620,000 × .836 = 1,107,382,000 lbs
= 1,107 m Btu

Steam Coal, 1994 = 64,673 tons

(Per HDC coal purch spec June 1994)

Btu content of coal = 64,673 tons × 2000 × 14,100 $\frac{BTU}{lb}$
= 1,824 m m Btu

Cost of treatment of Sulfuric System backwash water = – Utilities Cost Report

50 gpm ave × 60 $\frac{min}{hr}$ × 8760 × $.239/1000 gal = $6,500/yr.

Cost of Filter Water for feed water = – Utilities Cost Report

$\frac{1,324,620,000 \text{ lbs} \times \$0.148 / 1000 \text{gal}}{8 \text{ lbs water/gal}}$ = $24,500/yr

Cost of electricity (motors, precipitators, etc) =

– Cost ctr 2235 – per mar '95 elec bill

412,000 $\frac{KWH}{mo}$ (ave) × .035 $\frac{\$}{KWH}$ × 12 mo = $173,000/yr

Cost of fly ash disposal = 15,000 est
Cost of cinder removal = 10,000 est
[Cost of bldg maintenance = $393,391 routine + $529,104 major = $922,465
Cost of water treatment Chemicals (See Osmosis Study JLB 1995) $91,000

$$\text{Out of Pocket Steam Cost} = \frac{\text{Coal} + \text{electricity} + \text{water softening chemicals} + \text{FW} + \text{waste water treatment} + \text{fly ash} + \text{cinder disposal}}{\text{bldg steam output}}$$

per Defense Fuels, Geo. Tittsworth 3/95 — $2.91 million

$$OPSC = \frac{(\$45 \times 64,673) + \$173,000 + \$91,000 + \$24,500 + \$6,500 + 15,000 + 10,000}{1,107,382,000 \text{ lbs}}$$

$$= \frac{3.23 \text{ million}}{1,107} = \boxed{2.92 \ \frac{\$}{1000 \text{ lbs}}}$$

3.75 $\frac{\$}{K lbs}$ Counting Maintenance

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Calculations For: ECO No. 4

REF. SHULLER 18" PIPE W/ 1" INSUL. & METAL JACKET

AIR PREHEATER

$$Q_{ATMOS} = \frac{2792}{1000}(15\ FT) = 41.9\ MBH \ @\ 1200°\ OPER.\ TEMP$$

TAILGAS HTR

$$Q_{ATMOS} = \left(\frac{1345+1978}{2(1000)}\right)(21\ FT) = 34.9\ MBH \ @\ 900°$$

APPARENT PROD. GAS C_p FROM EXISTING SYST. CALCS:

$$C_p = \frac{[illegible]\ BTU}{17644\ \#/H(1470-1070)} = 0.434\ B/\#°F$$

NEW AIR PREHEATER LVG. PROD. GAS TEMP:

$$Q = 2086.1\ MBH + 41.9\ MBH = WC_p\Delta T = 17644(0.434)(\Delta T$$

$$\Delta T = 267.0$$

$$T_{LVG} = 1470 - 267.0 = 1203°F$$

APPARENT PROD. GAS C_p @ TAILGAS HEATER FROM EXISTG. SYSTEM CALCS.

$$Q = W\ C_p\ \Delta T = 1895.4(1000)$$

$$C_p = \frac{1895400}{17644(1070-785)} = 0.377\ B/\#°F$$

ASSUME 800°F NEW T.G. HTR. LVG. PROD. GAS. TEMP:

$$Q = \frac{17644}{1000}(0.377)(1203-800) = 2680.7\ MBH$$

$$T.G.\ \Delta T = \frac{2680.7/1000}{15050(0.24)} = 722°F \qquad T_{LVG} = 808°F$$

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Calculations For: ECO No. 4

USING GAS TABLES FOR AIR @ LOW PRESS:

$\overline{T_1} = 1265°R$

$h_1 = 308\ ^B/_{\#}$

$P_{r_1} = 29.23$

IDEAL CONDITIONS @ TURB EXH.:

$$P_{r_2} = P_{r_1}\left(\frac{P_2}{P_1}\right) = 29.23\left(\frac{14.7}{58+14.7}\right) = 5.91$$

$T_{2_{IDEAL}} = 815°R \longrightarrow 355°F$

$h_{2\,IDEAL} = 195.5\ ^B/_{\#}$

$EFF_{TURB} = 72.5\%$ FROM EARLIER CALCS

$$HP = \frac{15950\ ^{\#}/_{HR}\,(308\ ^B/_{\#} - 195.5\ ^B/_{\#})(.725)}{2545} = 495$$

$h_{EXH} = h_1 - (h_1 - h_{2\,IDEAL})(.725) = 226.4\ ^B/_{\#}$

$T_{EXH} = 941°R$ OR $480°F$

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Calculations For: TABLE 5

AMMONIA VAPORIZER, MIXER AND CONVERTER SAME AS TABLE 1.

AIR PREHEATER:

$Q_{REJ_{AIR}}$ = SAME AS TABLE 1

EXTRAPOLATED FROM SCHULER TABLE

$Q_{REJ_{ATMOS}} = (3000)(15) = 45000$ BTUH

$$T_{LVG} = T_{ENT} - \frac{Q_{AIR} + Q_{REJ_{ATMOS}}}{W C_P} = 1470 - \frac{2086056 + 45000}{17644(0.253)}$$

$= 992.6°F$

REVISE $Q_{REJ_{ATMOS}} = 2850(15) = 42750$ BTUH

$$T_{LVG} = 1470 - \frac{2086056 + 42750}{17644(0.253)} = 993.1°F$$

TAILGAS HEATER:

$T_{TG_{OUT}} = T_{TG_{IN}} + EFF(T_{PG_{IN}} - T_{TG_{IN}}) = 85 + 0.711(993 - 85)$

$= 730.6°F$

$Q_{REJ_{TG}} = W C_P \Delta T = 15450(0.248)(730.6 - 85)$

$= 2,473,635$ BTUH

$Q_{REJ_{ATMOS}} = 1100(21) = 23100$ BTUH

$$T_{PG_{OUT}} = T_{PG_{IN}} - \frac{(Q_{REJ_{TG}} + Q_{REJ_{ATMOS}})}{W C_P} = 992.6 - \frac{(2473635 + 23100)}{17644(0.253)}$$

$= 433.3°F$

REVISE $Q_{REJ_{ATMOS}} = \left(\frac{854 + 1345}{2}\right)21 = 23090 \rightarrow T_{PG_{OUT}} = 433.3°F$

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Calculations For: TABLE 5

CASCADE COOLER:

$Q_{REJ_{GAS}} = W_{DG}\, C_P \Delta T = 17092 (0.253)(433-105)$

$= 1,418,363$ BTU H

$Q_{REJ_{CONDENS}} =$ SAME AS TABLE 1 $= 673700$

ABSORPTION COLUMNS AND FINAL BLEACHER - SAME AS TABLE 1

TURBINE:

FROM KEENAN & KAYE @ 731°F (1191°R): $P_{r_1} = 23.35 \quad h_1 = 289.01$

$P_{r_2} = P_{r_1}\left(\frac{P_2}{P_1}\right) = 23.35\left(\frac{15}{73}\right) = 4.80$

THEOR. $h_2 = 184.72$ B/#

$h_2 = h_1 - E_{TURB}(h_1 - h_{2_{THEOR}}) = 289.1 - .725(289.1 - 184.7)$

$= 213.4$

$T_{EXH} = 889°R$ OR $429°F$

$WK_{TURB} = \frac{W(\Delta h)}{2545} = \frac{15450(289.01 - 213.4)}{2545} = 459$ HP

$Q_{REC} = 459(2545) = 1,168,175$ BTU H

$Q_{LOST} = W C_P \Delta T = 15450(0.248)(429-60)$

$= 1,413,860$

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Calculations For: TABLE 5

$$T_{EXH} = \frac{W_{ST}\, C_{P_{ST}}\, T_{ST} + W_G\, C_{P_G} T_G}{W_{ST}\, C_{P_{ST}} + W_G\, C_{P_G}} = \frac{2000(0.5)(400) + 15450(0.248)(535)}{2000(.5) + 15450(.248)}$$

$$= 507\,^{\circ}F$$

$$Wk_{TURB} = \frac{W_{ST}\, C_{P_{ST}}\, \Delta T_{ST} + W_G\, C_{P_G}\, \Delta T_G}{2545}$$

$$= \frac{2000(0.5)(731-400) + 15450(0.248)(731-535)}{2545}$$

$$= 425\ HP$$

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Calculations For: ECO No. 5

CURSORY EVALUATION:

REASONABLE ENERGY RECOVERY, IF IMPLEMENTED WITH ECO NO. 4, IS THE DIFFERENCE BETWEEN PREHEATER AND TAILGAS HEATERS LOSS TO ATMOSPHERE WITH & WITHOUT INSULATION

PREHEATER: $980.4 - 41.9 = 938.5$ MBH

TAILGAS HTR.: $554.3 - 34.9 = \underline{519.4}$ MBH

1457.9 MBH

ECO NO. 4 HEAT REMOVAL REQ'D TO KEEP TAILGAS TO TURBINE BELOW 750°F MFR'S. MAX. TEMP.:

$$Q = 15450(0.24)(805 - 745) = 222.5 \text{ MBH}$$

20 PSIG STEAM AVAILABLE @ STACK

$$Q = 15450(0.24)(480 - 275) = 760.1 \text{ MBH}$$

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Calculations For: ECO No. 5

TURBINE OUTPUT

$T_{IN} = 745°F$

$P_{r_1} = 24.38 \quad h_1 = 292.58$

$P_{r_2} = \frac{14.7}{72.7}(24.38) = 4.93$

$h_2 = 185.7$

$h_{EXH} = 292.58 - (292.58 - 185.7)(.725)$

$= 215.09$

$T_{EXH} = 435°F$

$HP = \frac{15450\,(292.58 - 215.09)}{2545} = 470.4$

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PDL	12-18-95	95094-00
Checked By:	Date:	Sheet No: ____ of ____

Calculations For: TABLE 6

AMMONIA VAPORIZER, MIXER, CONVERTOR, AIR PREHEATOR, CASCADE COOLER AND TURBINE: SAME AS TABLE 5

RECOVERY BOILER:

SATURATION TEMP @ 30 PSIG – 275°F

USING COUNTERFLOW WASTE HEAT BOILER, ASSUME OUTLET GAS TEMP (T_{TGOUT}) EQUALS 275°F

$$Q_{TG} = W\,C_p\,\Delta T = 15450\,(0.248)(429-275) = 590066 \text{ BTUH}$$

$$\text{STEAM} \rightarrow W = \frac{Q}{h_{ST}-h_{FW}} = \frac{590066}{1172.4-118.4} = 560 \text{ \#/HR}$$

$$Q_{LOST} = W\,C_p\,\Delta T = 15450(0.248)(275-60) = 823794$$

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PDL	11-13-95	95094-00
Checked By:	Date:	Sheet No: 1 of

Calculations For: ECO. NO. 6

PROCESS DRY AIR RATE:

$$M_D = M_w(1-w) = 19350 \text{ \#/HR} (1 - 0.0055) \text{ \#/\# DRY AIR}$$

$$= 19243.6 \text{ \#/HR DRY AIR}$$

CONVERT MFG. DESIGN CONDENSATE RATE TO PROCESS DRY AIR RATE:

$$1^{ST} \text{ STG CLR} = 216.4 \frac{(19243.6)}{27706} = 150 \text{ \#/HR}$$

$$2^{nd} \text{ " " } = 264.9 \frac{(19243.6)}{27706} = 184 \text{ \#/HR}$$

$$\text{AFTERCOOLER} = 173 \frac{(19243.6)}{27445} = 121 \text{ \#/HR}$$

$$455 \text{ \#/HR}$$

TURBINE ENTERING CONDITIONS:

MASS FLOW = 15450 + 1149 = 16599 #/HR

SPRAY MIX PROCESS:

$$Q = 1149 \text{ \#/HR} [(T_{MIX} - 207) + \overset{937.?}{h_{fg@25PSIA}} + (h_{g@T_{MIX}} - 1181.0)]$$

$$Q = 15450 \text{ \#/HR} (0.248 \text{ BTU/\#°F})(435 - T_{MIX})$$

$$T_{MIX} = 4566 - 0.235 h_g$$

T_{MIX}	h_g	ERROR
325	1189.2	-147.9
400	1229.9	-232.3
316	1184.2	-137.7

NOT ENOUGH HEAT IS AVAILABLE IN TAILGAS TO VAPORIZE THE CONDENSATE

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Checked By:	Date:	Sheet No: 2 of ____

Calculations For: ECO No. 6

EVALUATE FOR INCORPORATION W/ ECO No. 4

$$Q = 1149\ \text{\#/HR}\left[(T_{MIX} - 207) + 897.8 + h_g - 1181.0\right]$$

$$Q = 15450\,(0.248)(805 - T_{MIX})$$

$$T_{MIX} = 953.8 - 0.235\,h_g$$

T_{MIX}	h_g	ERROR
500°	1280.6	155.5
450°	1229.4	267.4
600°	1330.1	43.8
650°	1354.8	-12.0

USE 640°F TAILGAS/WATER VAPOR TEMP. @ TURBINE INLET.

$$h = \frac{[illegible]\ 265.9[illegible]) + 1149(1340.[illegible])}{16599} = 340.3\ \text{B/\#}$$

$P_{r_1} = 17.413$ $\qquad$ $S_1 = 1.81$

$P_{r_2} = 17.413\left(\frac{14.7}{72.7}\right) = 3.521$ $\qquad$ $h_{2\,IDEAL} = 1188$

$T_{2\,IDEAL} = 244°F$ $\qquad$ $T_{2\,IDEAL} = 285°F$

RECALCULATE USING TURBINE EXHAUST HT. RECOVERY TO CONDENSATE

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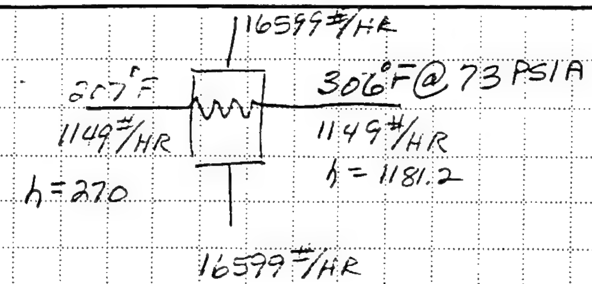
Checked By:	Date:	Sheet No: 3 of ___

Calculations For: ECO No. 6



① ASSUME 100% PHASE CHANGE OF CONDENSATE, W/ TAILGAS TEMP. LVG. THE HX = 220°F

H_2O SIDE $Q_{HX} = 1149\#/HR\,(h_{LVG} - h_{ENT}) = 1149(1181.2 - 270) = 1046969$

GAS SIDE $Q_{HX} = W_G C_{P_G} \Delta T + W_S C_{P_S} \Delta T = 15450(0.24)\Delta T + 1149(0.5)\Delta T$

$$\Delta T = \frac{1046969}{15450(0.24) + 1149(0.5)} = 244.5 \rightarrow T_{ENT\,G} = 220 + 244.5 = 464.5$$

STEAM/TAILGAS MIXTURE CONDITIONS:

$Q_{ST} = 1149(h_{@MIX} - 1181.2)$

$Q_{GAS} = 15450(0.24)(805 - T_{MIX})$

$T_{MIX} = 585.5 - 0.310\,h_{@MIX}$

T_{MIX}	h_{MIX}	ERROR
700	1380.2	-542
400	1231.6	-196
310	1183.8	-77.5

INSUFFICIENT HEAT IN TURBINE EXHAUST GAS TO VAPORIZE CONDENSATE

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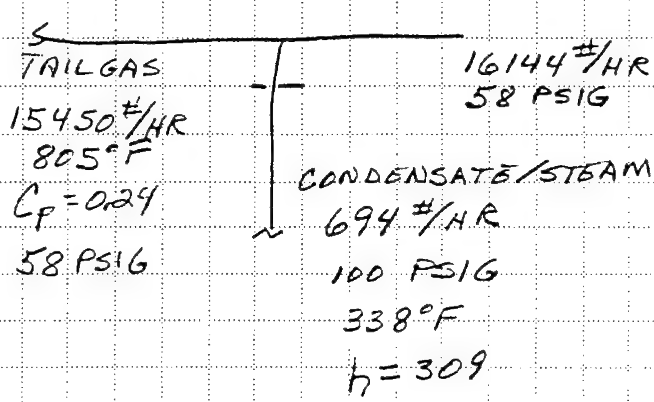
Checked By:	Date:	Sheet No: 4 of ____

Calculations For: ECO No. 6

CONSIDER DELIVERING AMMONIA VAPORIZER CONDENSATE ONLY:

* USE ORIFICE TRAP FOR CONTINUOUS DRAINAGE



$$15450(0.24)(805 - T_{mix}) = 694(h_{@mix} - 309)$$

$$T_{mix} = 862.8 - 0.187\, h_{@mix}$$

T_{MIX}	$h_{@MIX}$	ERROR (T_{MIX} - CALC)
750	1405	149.9
650	1355.5	40.7
540	1301.4	(79.4)
600	1330.9	(13.9)
615	1338.3	2.46

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Checked By:	Date:	Sheet No: 5 of

Calculations For: ECO No. 6

TURBINE PROCESS:

GAS

$P_{r_1} = 16.005 \quad h_1 = 259.7$

$P_{r_2} = \frac{14.7}{72.7}(16.005) = 3.236$

$T_2 = 227°$

$h_2 = 164.5$

$h_{EXH} = 259.7 - (259.7 - 164.5)(.725)$
$= 190.68$

$T_{EXH} = 335°$

VAPOR

$h_1 = 1338.3$

$s_1 = 1.80$

$h_2 = 1183$

$h_{EXH} = 1338.3 - (1338.3 - 1183).725$
$= 1230.5$

$T_{EXH} = 380°$

$$HP = \frac{15450(.24)(615-335) + 694(1338.3-1230.5)}{2545}$$

$= 437.3$

THIS CONCEPT IS ABANDONED

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Made By:	Date:	Job No:
PDL	12-12-95	95094-00
Checked By:	Date:	Sheet No: 22 of

Calculations For: ECO #7 ITERATION #1

WET GAS HEATER – 2000 #/HR STEAM + SPRAY

STEAM SATURATION TEMPER.

$$15405(0.246)(T_{WGIN} - 85) = 2000(0.50)(324 - T_{WGIN})$$

$$T_{WGIN} = \frac{2000(.5)(324) + 15405(.246)(85)}{15405(.246) + 2000(.5)} = 134.8^\circ F$$

$$Cp_{WG} = \frac{2000(.5) + 15405(.246)}{17405} = 0.275 \ B/\#^\circ F$$

$$T_{WG\,OUT} = T_{WGIN} + 0.711(T_{PGIN} - T_{WGIN}) = 134.8 + 0.711(993 - 134.8)$$

$$= 745.0^\circ F$$

$$\cancel{Q_{ATTEMPERATOR} = W_{WG}\, Cp_{WG}(T_{WGOUT} - 745) = 17405(0.275)(895.7-745)}$$

$$\cancel{= 721307 \ BTUH}$$

$$\cancel{W_{ATTEMPERATOR} = \frac{Q_{ATTEMPERATOR}}{h_{fg}} = \frac{721307}{891.7} = 809 \ \#/HR}$$

$$T_{PGOUT} = T_{PGIN} - \frac{W_{WG}\, Cp_{WG}(T_{WGOUT} - T_{WGIN}) + Q_{ATTEMPERATOR}}{w_{PG}\, Cp_{PG}}$$

$$= 1265 - \frac{17405(0.275)(895.7 - 134.8) + 721320}{17644(0.253)}$$

$$= 227.5^\circ F$$

CONDENSATION WILL OCCUR AT 254°F IN PRODUCT GAS.

$$Q_{PG\,ECONOMIZER} = 2000 \ \#/HR \ (1 \ B/\#^\circ F)(240 - 150) = 180000 \ BTUH$$

$$W_{PG\,COND} = \frac{Q_{PG\,ECON}}{h_{fg16}} = \frac{180000}{944} = 191 \ \#/HR$$

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Made By:	Date:	Job No:
PDL	12-12-95	95094-00
Checked By:	Date:	Sheet No: 23 of

Calculations For:

TURBINE

PARTIAL PRESSURE $H_2O = .175(58\text{ PSIG}) = 10.2\text{ PSIG}$ OR 25 PSIA

$S = 1.9764$

$h_{ST} = 1404.8$

THEOR. $h_{EXH_{ST}} = 1334$ @ 15 PSIA & $600°$

$h_{EXH_{ST}} = h_{ST} - 0.725(h_{ST} - 1334) = 1404.8 - 0.725(1404.8 - 1334)$

$= 1353.5\ B/\#$

$T_{EXH_{ST}} = 639°F$

GAS @ $745°F$:

$P_{r1} = 24.38$

$h_{1GAS} = 292.58\ B/\#$

$P_{r2} = P_{r1}\left(\frac{P_2}{P_1}\right) = 24.38\left(\frac{15}{73}\right) = 5.01$

THEOR. $h_{2GAS} = 186.46\ B/\#$

$h_{2EXH_G} = 292.58 - 0.725(292.58 - 186.46)$

$= 215.64\ B/\#$

$T_{2EXH_G} = 437°F$

$15405(0.246)(T_{EXH} - 437) = 2000(0.46)(639 - T_{EXH})$

$$T_{EXH} = \frac{15405(.246)(437) + 2000(0.46)(639)}{15405(0.246) + 2000(0.46)} = 476.5°F$$

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Made By: PDL	Date: 12-12-95	Job No: 95094-00
Checked By:	Date:	Sheet No: 24 of ____

Calculations For:

$$C_{P_{EXH}} = \frac{W_{EXHG} C_{P_{EXHG}} + W_{EXHST} C_{P_{EXHST}}}{W_{EXH}} = \frac{15405(0.246) + 2000(0.46)}{17405} = 0.271$$

$$WK_{TURB} = \frac{W_{EXH} C_{P_{EXH}} (745 - T_{EXH})}{2545}$$

$$= \frac{17405(.271)(745 - 476.5)}{2545} = 497\ HP$$

WASTE HEAT BOILER

$T_{STACK} = 260°F$ — ASSUMED

$$Q_{BLR} = W_{EXH}\ C_{P_{EXH}} (T_{EXH} - 250) = 17405(0.263)(492-260)$$

$= 1061983$ - BTUH

$$W_{STEAM} = \frac{Q_{BLR}}{h_{fg}} = \frac{1061983}{891.7} = 1191\ \#/HR$$

TOTAL H_2O ADDED TO TAILGAS:

~~809~~ #/HR
1191 #/HR
~~2000~~ #/HR — ASSUMED 2000 #/HR

PARTIAL PRESSURE OF H_2O @ STACK:
$P = 0.175(14.696) = 2.57$ PSIA
DEW POINT = 136°F

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Checked By:	Date:	Sheet No: ____ of ____

Calculations For: ECO #7 ITERATION 2

CASE A   1800 #/HR SATURATED STEAM @ 80 PSIG INJECTED

WET GAS CONDITIONS:

$$W_{TG}\, C_{P_{TG}} (T_{WG} - 85) = W_{ST}\, C_{P_{ST}} (T_{SAT} - T_{WG})$$

$$[15405(0.248) + 1800(0.5)]\, T_{WG} = 1800(.5)(324) + 15405(0.248)(85)$$

$$T_{WG} = 130.6\,°F$$

$$C_{P_{WG}} = \frac{W_{TG}\, C_{P_{TG}} + W_{ST}\, C_{P_{ST}}}{W_{WG}} = \frac{15405(0.248) + 1800(0.5)}{17205} = 0.274\ B/\#°F$$

$$T_{WG_{OUT}} = T_{WG} + EFF(T_{PG_{IN}} - T_{WG}) = 130.6 + 0.711(993.1 - 130.6)$$

$$= 743.8$$

$$T_{PG_{OUT}} = T_{PG_{IN}} - \frac{Q_{WG} + Q_{RETAIN}}{W_{PG}\, C_{P_{PG}}} = 993.1 - \frac{17205(0.274)(743.8 - 130.6) + 41024}{17644(0.253)}$$

$$= 336.3\,°F$$

ECONOMIZER:

$$Q_{FW} = W_{FW}\, C_{P_{FW}}\, \Delta T_{FW} = 1800(1)(324 - 150) = 313200 \text{ BTUH}$$

$$T_{PG_{OUT}} = T_{PG_{IN}} - \frac{Q_{FW}}{W_{PG}\, C_{P_{PG}}} = 336.3 - \frac{313200}{17644(0.253)} = 266.1\,°F$$

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Made By:	Date:	Job No:
Checked By:	Date:	Sheet No: ____ of ____

Calculations For: TABLE 7

TURBINE:

PERCENT STEAM BY VOLUME:

$$MOL_{ST} = \frac{1800}{18.016} = 99.9$$

$$MOL_{TG} = 546.73$$

$$\% = \frac{99.9(100)}{546.73+99.9} = 15.45$$

INLET STEAM PARTIAL PRESSURE = 0.1545(58) = 8.96 PSIG

$h_{ST_{IN}} = 1407.3$ $S_{ST_{IN}} = 1.983$

OUTLET STEAM PARTIAL PRESSURE = 0.1545(16) = 2.47 PSIA

THEOR. $h_{ST_{OUT}} = 1186.3$ $S = 1.5815$

$h_{ST_{OUT}} = h_{ST_{IN}} - .725(1407.3 - 1186.3) = 1247.1$

$T_{ST_{OUT}} = 412°F$

INLET GAS PARTIAL PRESS = 58 − 9 = 49

$P_{r_1} = 24.31$ $h_1 = 292.33$ → @ 744°F

THEORETICAL $P_{r_2} = P_{r_1}\left(\frac{P_2}{P_1}\right) = 24.31\left(\frac{16}{63.7}\right) = 5.93$

THEOR. $h_2 = 195.71$

$h_2 = 292.33 - 0.725(292.33 - 195.71) = 222.28$

$T_2 = 925°R$ OR 465°F

P10069

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	Checked By:	Date:	Sheet No: ___ of ___

Calculations For: TABLE 7

$$W_{ST} C_{P_{ST}} (T_{EXH} - T_{ST_{OUT}}) = W_{GAS} C_{P_{GAS}} (T_2 - T_{EXH})$$

$$[1800(0.47) + 15405(0.248)] T_{EXH} = 15405(0.248)(465) + 1800(0.47)(412)$$

$$T_{EXH} = 455.4^\circ F$$

$$h_{INLET} = \frac{W_{ST} h_{ST_{IN}} + W_G h_1}{W_{ST} + W_G} = \frac{1800(1407.3) + 15405(292.33)}{1800 + 15405}$$

$$= 409.0 \ B/\#$$

$$h_{EXH_2} = \frac{W_{ST} \ h_{ST_{OUT}} + W_G h_2}{W_{ST} + W_G} = \frac{1800(1247.1) + 15405(222.28)}{1800 + 15405}$$

$$h_{EXH} = 329.5 \ B/\#$$

$$WK_{TURB} = \frac{(17205)(409.0 - 329.5)}{2545} = 537.4 \ HP$$

$$Q_{REL} = 537.4(2545) = 1,367,798 \ BTUH \quad @ \ TURBINE$$

$$Q_{REJ} = W C_P \Delta T = 17205(0.274)(455.4 - 60) = 1,863,983 \ BTUH$$

WASTE HEAT BOILER:

$$Q = W_{ST} h_{fg} = 1800(891.7) = 1,605,060 \ BTUH$$

$$T_{STACK} = T_{EXH} - \frac{Q}{W_{EXH} C_{P_{EXH}}} = 455.4 - \frac{1605060}{17205(0.274)} = 115^\circ F$$

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Checked By:	Date:	Sheet No: ____ of ____

Calculations For: ECO #7 ITERATION 3

CASE B 1500 #/HR SATURATED STEAM @ 80 PSIG INJECTED

SUBSTITUTION OF 1500#/HR IN FORMULAE OF CASE GIVES THE FOLLOWING RESULTS:

WET GAS CONDITIONS:

$T_{WG} = 124.2°F$
$C_{P_{WG}} = 0.270\ B/\#°F$
$T_{WG_{OUT}} = 742.0°F$

$T_{PG_{OUT}} = 352.2°F$

ECONOMIZER:

ALLOW OUTLET OF ECONOMIZER TO CONTAIN SMALL PERCENTAGE OF STEAM SUCH THAT $T_{PG\,OUT} = 265°F$

$$Q_{FW} = W_{FW} \Delta h_{FW} = W_{PG} C_{P_{PG}} \Delta T_{PG}$$

$$\Delta h_{FW} = \frac{17644(0.253)(352.2 - 265)}{1500} = 259.5\ B/\#$$

$$Q_{FW_{SENS}} = W_{FW} C_{P_{FW}} \Delta T = 1500(1)(324 - 150) = 261000\ BTUH$$

FW EQUILIBRIUM:

$$W_{STEC} = \frac{W_{FW} \Delta h_{FW} - Q_{FW_{SENS}}}{h_{fg}} = \frac{1500(259.5) - 261000}{891.7} = 143.8\ \#/HR$$

$$Q_{REC} = W_{FW} \Delta h_{FW} = 1500(259.5) = 389250\ BTUH$$

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Made By:	Date:	Job No:
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Calculations For:

TURBINE:

$MOL_{ST} = 83.26$

$MOL_{TG} = 546.73$

$\% = 13.22$

PARTIAL $P_R = .1322(58) = 7.67\ PSIG \longrightarrow 22.37\ PSIA$ INLET

$h_{STIN} = 1403.4$ @ 742°F $\quad S_{STIN} = 1.985$

PARTIAL $P_R = .1322(16) = 2.11\ PSIA$

THEOR $h_{STOUT} = 1159 \quad S = 1.985$

$h_{STOUT} = 1403.4 - .725(1403.4 - 1159) = 1226.2$

$T_{STOUT} = 367°F$

GAS PARTIAL $P_R = 58 - 7.67 = 50.3\ PSIG$ OR $65.0\ PSIA$

$P_{r1} = 24.16 \quad h_1 = 291.81 \longrightarrow$ @ 742°F

$P_{r2} = 24.16\left(\frac{16}{65}\right) = 5.95$

THEOR $h_2 = 195.9$

$h_2 = 291.81 - 0.725(291.81 - 195.9) = 222.28$ B/#

$T_2 = 465°F \quad h_{EXH} = 311.4$ B/#

$T_{EXH} = 449.7 \quad W_{KTURB} = 525\ HP$

$h_{INLET} = 390.4$

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Checked By:	Date:	Sheet No: ___ of ___

Calculations For:

WASTE HEAT BOILER:

$$Q = (W_{ET} - W_{STACK})\,h_{fg} = (1500 - 143)(891.7) = 1210037 \text{ BTUH}$$

$$T_{STACK} = T_{EXH} - \frac{Q}{W_{EXH}\,Cp_{EXH}} = 449.7 - \frac{1210037}{16905(0.275)} = 189.4^{\circ}F$$

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Made By:	Date:	Job No:
Checked By:	Date:	Sheet No: ____ of ____

Calculations For: ECO #7 - ITERATION 4

CASE C   1400 #/HR STEAM @ 80 PSIG INJECTED @ TAILGAS & WITH PRODUCT GAS LEAVING THE HEAT RECOVERY UNIT AT 245°F

WET GAS CONDITIONS:

$W_{TG} C_{P_{TG}} (T_{WG} - 85) = W_{ST} C_{P_{ST}} (T_{SAT} - T_{WG})$

$[15405(0.248) + 1400(0.47)] T_{WG} = 1400(0.47)(324) + 15405(0.248)(85)$

$T_{WG} = 120.1\,°F$

$C_{P_{WG}} = \dfrac{W_{TG} C_{P_{TG}} + W_{ST} C_{P_{ST}}}{W_{TG} + W_{ST}} = \dfrac{15405(0.248) + 1400(0.47)}{15405 + 1400} = 0.266\ B/\#°F$

$T_{WG_{OUT}} = T_{WG} + EFF(T_{PG_{IN}} - T_{WG}) = 120.1 + 0.711(993.1 - 120.1)$

$= 740.8\,°F$

$T_{PG_{OUT}} = T_{PG_{IN}} - \dfrac{Q_{WG} + Q_{RELATIVES}}{W_{PG} C_{P_{PG}}} = \dfrac{(15405+1400)(0.266)(740.8-120.1) + 41024}{17644(0.253)}$

$= 993.1 - 630.8 = 362.3\,°F$

ECONOMIZER:

$Q_{FW} = W_{PG} C_{P_{PG}} \Delta T_{PG} = 17644(0.253)(362.3 - 245)$

$= 523619$ $\Delta h_{FW} = \dfrac{523619}{1400} = 374.0\ B/\#$

$Q_{FW_{SENS}} = W_{FW} C_{P_{FW}} \Delta T_{FW} = 1400(1)(324 - 150) = 243600\ BTU/H$

$W_{STEC} = \dfrac{W_{FW} \Delta h_{FW} - Q_{FW_{SENS}}}{h_{fg}} = \dfrac{1400(374.0) - 243600}{891.7} = 314\ \#/HR$

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Made By:	Date:	Job No:
Checked By:	Date:	Sheet No: ____ of ____

Calculations For:

TURBINE:

$$MOL_{ST} = \frac{1400}{18.016} = 77.7$$

$$MOL_{TL} = 546.73$$

$$\% = \frac{77.7}{546.73+77.7} = 12.44$$

INLET STEAM PARTIAL PRESSURE = .1244 (58) = 7.22 PSIG

$h_{STIN} = 1402.9$ $S_{STIN} = 1.9889$

OUTLET STEAM PARTIAL PRESSURE = .1244 (16) = 1.99 PSIA

THEOR. $h_{STOUT} = 1151.4$ B/#

$$h_{STOUT} = h_{STIN} - 0.725(h_{STIN} - 1151.4) = 1402.9 - .725(1402.9 - 1151.4)$$

$$= 1220.5 \text{ B/\#}$$

$$T_{STOUT} = 354.3°F$$

INLET GAS PARTIAL PRESS. = 58 - 7.22 = 50.78 PSIG @ 741°F OR 1201°R

$P_{r_1} = 24.08$ $h_1 = 291.56$

$$P_{r_2} = P_{r_1}\left(\frac{16}{50.78}\right) = 7.59$$

THEOR $h_2 = 210$

$$h_2 = h_1 - EFF(h_1 - 210) = 291.56 - .725(291.56 - 210)$$

$$= 232.4$$ $T_2 = 506°F$

P10069

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Checked By:	Date:	Sheet No: ____ of ____

Calculations For:

$$W_S\, Cp_{ST}(T_{EXH} - T_{STOUT}) = W_{GAS}\, Cp_{GAS}(T_2 - T_{EXH})$$

$$[1400(0.47) + 15405(0.248)]\, T_{EXH} = 15405(0.248)(506) + 1400(.47)(354)$$

$$T_{EXH} = 483.7\,°F$$

$$h_{INLET} = \frac{W_{ST} h_{STIN} + W_G h_1}{W_{ST} + W_G} = \frac{1400(1402.9) + 15405(291.56)}{1400 + 15405}$$

$$= 384.1\ B/\#$$

$$h_{EXH} = \frac{W_{ST} h_{STOUT} + W_G h_2}{W_{ST} + W_G} = \frac{1400(1220.5) + 15405(232.4)}{1400 + 15405}$$

$$= 314.7\ B/\#$$

$$W_{KTURE} = \frac{(1400 + 15405)(384.1 - 314.7)}{2545} = 458\ HP$$

$$Q_{RSC} = 458(2545) = 1165979\ BTUH$$

WASTE HEAT BOILER:

$$Q = (W_{ST} - W_{STECON})\, h_{fg} = (1400 - 314)(891.7) = 968386\ BTUH$$

$$T_{STACK} = T_{EXH} - \frac{Q}{W_{WG}\, Cp_{WG}} = 483.7 - \frac{968386}{16805(0.266)}$$

$$= 267.1\,°F$$

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Calculations For: ECO #7 ITERATION 5

FINAL CASE: STEAM ~~& SPRAYWATER~~ INJECTED @ TAILGAS LEAVING TAILGAS HEATER & WITH WASTE HEAT BOILERS IN BOTH TURBINE EXH. GAS & PRODUCT GAS LVG TAILGAS HEATER

WET GAS CONDITIONS: (USING ECO #4 RESULTS)

$$W_{TG}\,C_{P_{TG}}(T_{TG}-T_{WG}) = W_{ST}\,C_{P_{ST}}(T_{WG}-T_{SAT})$$

$$[15405(0.248)+1500(0.47)]T_{WG} = 1500(0.47)(324)+15405(0.248)(731)$$

$$T_{WG} = \cancel{888.8}\ 667.6\ °F$$

~~ATTEMPORATOR SPRAY:~~

~~MFRS TURBINE INLET MAXIMUM MINUS 5°F~~

$$\cancel{Q_{AT} = W_{WG}\,C_{P_{WG}}(T_{WG}-745) = (15405+1500)(0.270)(888.8-745)}$$

$$\cancel{= 656259\ BTUH}$$

$$\cancel{W_{AT} = \frac{Q_{AT}}{h_{fg}} = \frac{656259}{891.9} = 736\ \#/HR}$$

PRODUCT GAS WASTE HEAT BOILER:

* WITH 150°F FEEDWATER, ASSUME PRODUCT GAS LEAVING BOILER @ ~~225~~ 250 °F

$$Q_{REC} = W_{PG}\,C_{P_{PG}}(T_{PG_{OUT}} - \cancel{225}\ 250) = 17644(0.253)(433 - \cancel{225}\ 250)$$

$$= \cancel{928498}\ 816900 \quad \text{W.O. CONSIDERING CONDENSATION}$$

$$W_{STPG} = \frac{Q_{REC}}{C_{P_{FW}}\,\Delta T_{FW} + h_{fg}} = \frac{928498}{(1)(324-150)+891.7} = \cancel{871}\ 766\ \#/HR$$

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	Checked By:	Date:	Sheet No: ____ of ____
Calculations For:			

TURBINE:

$$MOL_{H_2O} = \frac{1500 + \cancel{736}}{18.016} = \cancel{124.1}\ 83.3$$

$$MOL_{TG} = 546.73$$

$$\% = \frac{\cancel{124.1}\ 83.3}{546.73 + \cancel{124.1}\ 83.3} = \cancel{18.5}\ 13.2$$

STEAM PARTIAL PRESSURE $= 0.\cancel{185}\,132\,(58) = \cancel{10.73}\ 7.67$ PSIG INLET

$= 0.185\,(16) = \cancel{2.96}\ 2.11$ PSIA OUTLET

$h_{STIN} = \cancel{1404.8}\ 1404.9$ B/# @ 745°F $\quad S_{STIN} = 1.974$

THEOR $h_{STOUT} = 1180.7$ B/#

$$h_{STOUT} = h_{STIN} - EFF(h_{STIN} - 1180.7) = 1404.8 - 0.725(1404.8 - 1180.7)$$
$$= 1242.3 \text{ B/\#}$$

$$T_{STOUT} = 402°F$$

TAILGAS:

$P_{r_1} = 24.38$ @ 1205°R $\quad h_{TG1} = 292.58$

$$P_{r_2} = P_{r_1}\left(\frac{16}{70}\right) = 5.57$$

THEOR. $h_2 = 192.30$

$$h_2 = h_{TG1} - EFF(h_{TG1} - 192.3) = 292.58 - 0.725(292.58 - 192.3)$$
$$= 219.9 \text{ B/\#} \qquad T_{TGOUT} = 455°F$$

$$W_{KTURB} = \frac{W_{ST}\Delta h_{ST} + W_G \Delta h_G}{2545} = \frac{\cancel{2236}\ 1500(1404.8 - 1242.8) + 15405(292.58 - 219.9)}{2545}$$

$= \cancel{582}\ 535$ HP

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Checked By:	Date:	Sheet No: ____ of ____

Calculations For:

TURBINE EXHAUST WASTE HEAT BOILER:

$$W_{ST_{TG}} = \frac{W_{STPG} C_{PST}(T_{STOUT} - \cancel{225}^{250}) + W_{TG} C_{PTG}(T_{TGOUT} - \cancel{225}^{250}) \cancel{- W_{AT} C_{PAT}(324-150)}}{C_{PFW} \Delta T_{FW} + h_{fg}}$$

$$= \frac{\cancel{871}^{766}(0.47)(402 - \cancel{225}^{250}) + 15405(0.248)(455 - \cancel{225}^{250}) \cancel{- 736(174)}}{(324-150) + 891.7}$$

$$= \cancel{845}^{786} \text{ \#/HR}$$

$$\text{TOTAL STEAM} = \cancel{871}^{766} + \cancel{845}^{786} = \cancel{1716}^{1552} \text{ \#/HR}$$

$$\frac{W_{ST\ ASSUMED}}{1716} = \frac{\Delta T_{REC}}{440-225}$$

$$440 - T_{LVG} = \frac{1500(440-225)}{1716}$$

$T_{LVG} = 252°F$ ← USE THIS FOR RECOVERY BOILER OUTLET TEMP.

$$W_{ST} C_{PST}(T_{EXH} - 402) = W_{TG} C_{PTG}(455 - T_{EXH})$$

$$T_{EXH} = \cancel{426}^{446} °F$$

$$Q_{LOST} = W_{EXH} C_{PEXH} \Delta T_{STK} = \cancel{17640}^{16905}(0.275)(250-60)$$

$$= \cancel{921690}^{883286}$$

$$Q_{REJ} = W_{EXH} C_{PEXH}(T_{EXH} - T_{STK}) = \cancel{17640}^{16905}(0.275)(\cancel{433}^{446} - 60) = \cancel{1809423}^{1794466}$$

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Calculations For: ECO #7A

$W_{ST} = 1200\ \#/HR$ – CLAYTON QUOTATION

$$\frac{T_{WG2} - T_{WG1}}{T_{PG1} - T_{WG1}} = 0.711$$

$$T_{WG2} = T_{WG1} + 0.711(T_{PG1} - T_{WG1})$$

$$W_{ST}\, C_{P_{ST}} (T_{ST} - T_{WG1}) = W_{TG}\, C_{P_{TG}} (T_{WG1} - T_{TG})$$

$$1200(0.47)(324 - T_{WG1}) = 15405(0.248)(T_{WG1} - 85)$$

$$T_{WG1} = \frac{15405(0.248)(85) + 1200(0.47)(324)}{15405(0.248) + 1200(.47)} = 115.7°F$$

$$T_{WG2} = 115.7 + 0.711(993 - 115.7) = 739.5°F$$

$$T_{PG2} = T_{PG1} - \frac{Q_{RECOV}}{W_{PG}\, C_{P_{PG}}} = 993 - \frac{(15405 + 1200)(0.275)(739.5 - 115.7)}{17644(0.258)}$$

$$= 367.3°F$$

TURBINE:

WG CONSTITUENT	# MOLES/HR
N_2	505.16
A	6.21
NO	30.62
H_2O	$4.74 + \frac{1200}{18.016} = 71.35$
	613.34

$$H_2O\ \%\ \text{BY VOL} = \frac{71.35(100)}{613.34} = 11.6$$

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Calculations For:

H_2O PARTIAL PRESS $= (58+14.7)(.116) = 8.43$ PSIA

$h_G = 1403.5$ @ $739.5°F$

$S_G = 2.0667$

THEOR. $h_2 = 1255.4$

$h_2 = 1255.4 - .725(1403.5 - 1255.4) = 1296.1$ $T_{EXH} = 517°F$

$P_{R1} = 23.94$ $h_{G1} = 291.05$

$P_{R2} = P_{R1}\left(\frac{15}{64.3}\right) = 5.58$

THEOR $h_2 = 192.3$

$h_{WG2} = 291.05 - .725(291.05 - 192.3) = 211.34$

$T_{WG2} = 420°F$

$$W_{KTURB} = \frac{1200(1403.5 - 1296.1) + 15405(291.05 - 211.34)}{2545}$$

$= 533$ HP

$1200(.47)(517 - T_{WG2}) = 15405(.275)(T_{WG2} - 420)$

$T_{WG2} = 432°F$

63°F LESS THAN BASIS FOR CLAYTON QUOTATION

ASSUME SYSTEM W.O. PR.GAS RECOV & W/ STEAM INJECTED IN TAILGAS @ OUTLET OF ABSORPTION COLUMN WILL PRODUCE 525 HP.

P10069

AEI AFFILIATED ENGINEERS SE, INC. 3300 SW Archer Road Gainesville, Florida 32608 (904) 376-5500 FAX (904) 375-3479	Made By: PDL	Date: 12-12-95	Job No: 95094-00
	Checked By:	Date:	Sheet No: ____ of ____

Calculations For: TURBINE INLET/OUTLET PIPING.

WET GAS LEAVING HEATER:

~~17405~~ 16905 #/HR @ 745°F

DRY GAS = 15320 #/HR

H_2O VAPOR = ~~2085~~ 1500 #/HR

CONSTITUENTS	# MOLES/HR	% BY VOLUME
DRY GAS	541.99	~~82.4%~~ 86.7
H_2O	~~2085~~ 1500/18.015 = ~~115.74~~ 83.26	~~17.6%~~ 13.3
	~~657.73~~ 625.25	

H_2O PARTIAL PRESSURE = $0.\cancel{176}\,133\,(58) = \cancel{10.2}\;7.7$ PSIG

$$v_{DG} = \frac{P_{ATM}\, v_{ATM}\,(T_{DG})}{T_{ATM}\,(P_{DG})} = \frac{14.7(13.07)(\cancel{1205}\;455\,440)}{518.7\,(58-\cancel{10.2}\,7.7+14.7)} = \cancel{7.14}\;5.21\ FT^3/\#$$

$v_{H_2O} = \cancel{28.64}\;18.38\ FT^3/\#$ FROM KEENAN & KEYES

$$v_{WG} = \frac{15320(\cancel{7.14}\;5.21) + \cancel{2085}\;1500(\cancel{28.64}\;18.38)}{\cancel{17405}\;16905} = \cancel{9.72}\;6.35\ FT^3/\#$$

$$\text{VELOCITY} = \frac{\cancel{17405}\;16905\ \#/HR\,(\cancel{9.72}\;6.32\ FT^3/\#)(144\ IN^2/FT^2)}{60\ M/HR\,(31.7\ IN^2)} = \cancel{12{,}804}\;8089\ FPM$$

$$N_{RE} = \frac{V D \rho}{\mu} = \frac{(\cancel{12804}\;8089\ FT/MIN)(6.357\ IN)(0.07651\ \#/FT^3)}{(218\times10^{-7}\ \#/SEC\text{-}FT)(60\ SEC/MIN)(12\ IN/FT)}$$

$= \cancel{396759}\;250648$

$$\Delta P = \frac{3.4\times10^{-6} f L W^2 v}{d^5} = \frac{(3.4\times10^{-6})(0.018)(100)(17405)^2(9.72)}{(6.357)^5}$$

$= 1.5$ PSI

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PDL	12-12-95	95094-00
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Calculations For:

TURBINE EXHAUST VELOCITY

$$v_2 = \frac{(72.7\ PSIA)(\overset{6.35}{\cancel{9.72}}\ FT^3/\#)(\overset{446+460}{\cancel{952}}\ °F)}{(\underset{745+460}{\cancel{1205}}\ °F)(15.3\ PSIA)} = \overset{22.68}{\cancel{36.49}}\ FT^3/\#$$

$$VELOCITY = \frac{\overset{16905}{\cancel{17405}}\ \#/HR(\overset{22.68}{\cancel{36.49}}\ FT^3/\#)(144\ IN^2/FT^2)}{60\ M/HR(111.93\ IN^2)} = \overset{8220}{\cancel{13,618}}\ FPM$$

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Calculations For: ECO SAVINGS

No. 1 $266543

OPERATING HOURS PER YEAR = 4 D/MO (24 H/D)(12 MO/YR) = 1152

ELECT. SAVINGS = 2.0182 x 10^6 BTU (1152 H/YR) = 2324.96 MIL. B/YR

STEAM INCREASE = 12.7855 x 10^6 BTU (1152 H/YR) = 10537.79 "

DEMAND = 793(.748) = 593.16 KW → $13050

No. 2 $192277

ELECT. INCREASE = (2786.8 - 2018.2)(1152) / 1000 = 885.427 "

STEAM OFFSET = 2990.8 (1152) / 1000 = 3445.402 "

DEMAND = -302(.748) = -225.90 → -$4970

No. 3 $31200

No. 4 $4850

ELECT. SAVINGS = (2018.2 - 1618.6)(1152) / 1000 = 460.339

COST - $4850

DEMAND = (793 - 636)(.748) = 117.44 → $2585

No. 5 $27000 + $4850 = $31850

ELECT. SAVINGS = (2018.2 - 1618.61)(1152) = 460.339

STEAM OFFSET = 560/694 (714.1)(1152) = 663.804

STEAM PLANT MAKEUP = (694-560)(1152) = 154368 #/YR

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Calculations For:

No. 7

ELECT SAVINGS = $(2018.2 - 1425.2)\frac{(1152)}{1000}$ = 683.136

ADDTL. STEAM PLANT MAKEUP = 420 #/HR (1152) = 483840 #/YR

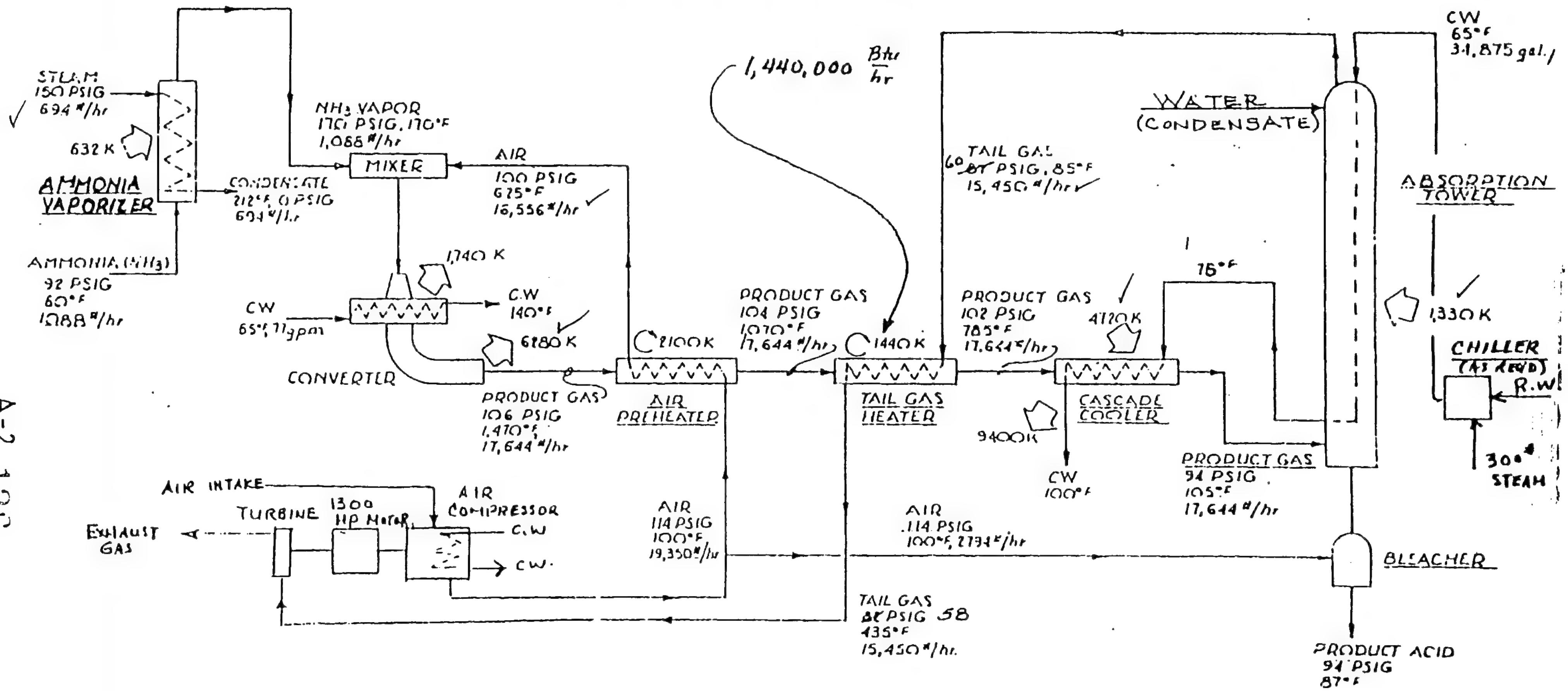
$412 ANNUAL RECCURING EXP.

DEMAND = (743 - 560).748 = 174.28 → $3835

P10069

REFERENCE MATERIAL

ENERGY BALANCE-BLDG. 302-B
NITRIC ACID MANUFACTURING



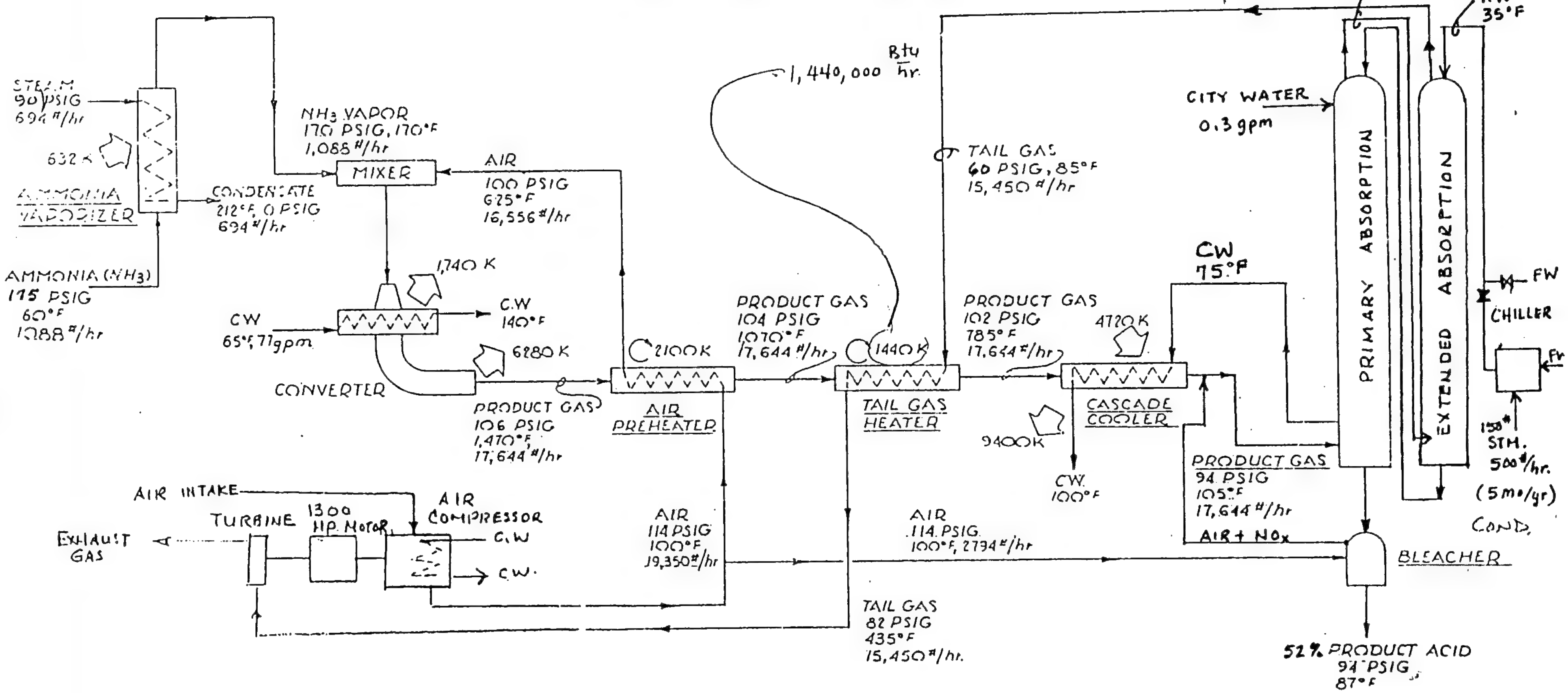
AS BUILT JAN 1995

HOLSTON ARMY AMMUNITION PLANT HOLSTON DEFENSE CORPORATION KINGSPORT, TENN. BLDG. 302-B, NITRIC ACID MFG.	DRAWN-PB DATE-8-14-76 APP'D- SK# 2286

FIGURE 16

65°F
34,875 GAL/HR

ENERGY BALANCE-BLDG. 302-B NITRIC ACID MANUFACTURING



AS-BUILT APRIL 1995 J Bouchillon

HOLSTON ARMY AMMUNITION PLANT HOLSTON DEFENSE CORPORATION KINGSPORT, TENN. BLDG. 302-B, NITRIC ACID MFG.	DRAWN-P DATE-2-14- APP'D-NG SK# 2286

55 TPD UNIT

FIGURE 16

Technical Report No. HDC-39-77

HOLSTON ARMY AMMUNITION PLANT
PROCESS ENERGY INVENTORY
NITRIC ACID MANUFACTURING, BUILDING 302-B

Equipment	Heat Added 1000 Btu/hr	Heat Added Source	Heat Added lb/hr	Heat Recovered 1000 Btu/hr	Heat Recovered Donor	Heat Recovered Recipient	Heat Removed 1000 Btu/hr	Heat Removed Source	Heat Removed Gal/min	Heat Lost 1000 Btu/hr	Heat Lost Source	Heat Lost Rate	Comments
Ammonia Vaporizer	631.9	Steam	694							69.4		.2 gpm	Basis: 45 TPD production.
Converter	6280	Reaction		563	Ammonia	Product Gas	1,740	R.W.	77.5				
				2100	Air	Product Gas							
PRE-Compressor	1536	Elect.					3,400	R.W.	329				
										307	Machine		Mechanical & electrical losses
XRD-Compressor				1082	Tail Gas	Air				60	Exhaust Gas		318.8 hp-hr/hr 75% turbine efficiency.
Air Preheater							2,100	Air	16,556*				
Tail Gas Heater							1,440	Tail Gas	15,450*				*Pounds per hour.
Cascade Cooler	4733	Reaction	17,644				7,963	R.W.	581				
Absorption Tower	1331	Reaction					1,453	R.W.	581				
	16.3	Condensate Feed	1,256										
Bleacher										112.5	61% Acid	6147 lb/hr	
Total Process Energy	18,273 Added or Recovered						18,645 Removed or Lost						Imbalance - 2%

$\frac{6147(30)(.61)}{2000} = 45T$

Holston Defense Corporation

TABLE 28

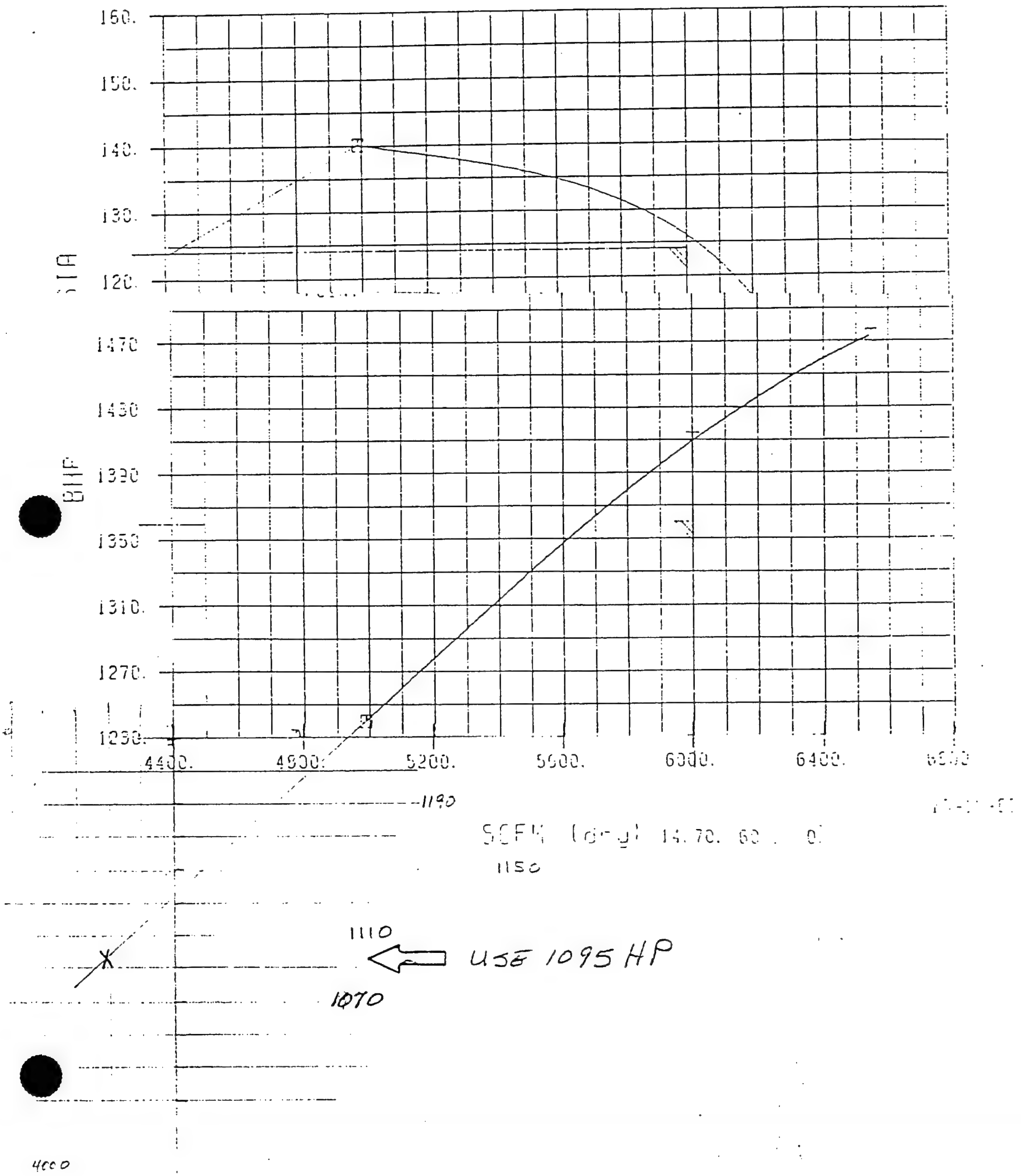
Kingsport, Tennessee

EMC ENGINEERS, INC.
PROJ. # ______ PROJECT ______
SHEET NO. ______ OF ______
CALCULATED BY ______ DATE ______
CHECKED BY ______ DATE ______
SUBJECT ______

JOY MANUFACTURING CO. BUFFALO N.Y.

TEST PERFORMANCE F07693M1 CUSTOMER WITNESS TEST

7693 HOLSTEN DEFENSE CORP 197052



vapor pressures (p, psia) at various temperatures (t, deg F) are as follows:

t	200	250	300	350	400	450	500
p	0.060	0.227	0.701	1.832	4.117	8.638	16.29
t	550	600	650	700	750	800	
p	28.54	47.01	73.55	110.1	158.6	221.0	

Dowtherm A is the eutectic mixture of diphenyl oxide and diphenyl containing 73.5 percent of diphenyl oxide and 26.5 percent of diphenyl and melting at 53.6°F. It is used as a liquid heating medium at elevated temperatures. Its low vapor pressure permits high temperature without attendant high pressures. Table 32 (Badger, *Ind. Eng. Chem.*, Sept., 1937) gives properties of this eutectic.

Pure Hydrocarbons The vapor pressures of various commercially important pure hydrocarbons are shown graphically in Fig. 25.

Ammonia Vapor The properties of saturated and superheated ammonia vapor have been determined accurately by the NBS (*Circ.* 142, 1923). The principal properties are given in Tables 33 and 34 and Fig. 24. Properties of **aqua-ammonia** are given in Fig. 26.

In these tables, the entropy s_f and the heat of the liquid h_f are taken as zero at −40°F instead of at 32°F, as is customary in most tables.

Properties of Other Refrigerants Complete and consistent

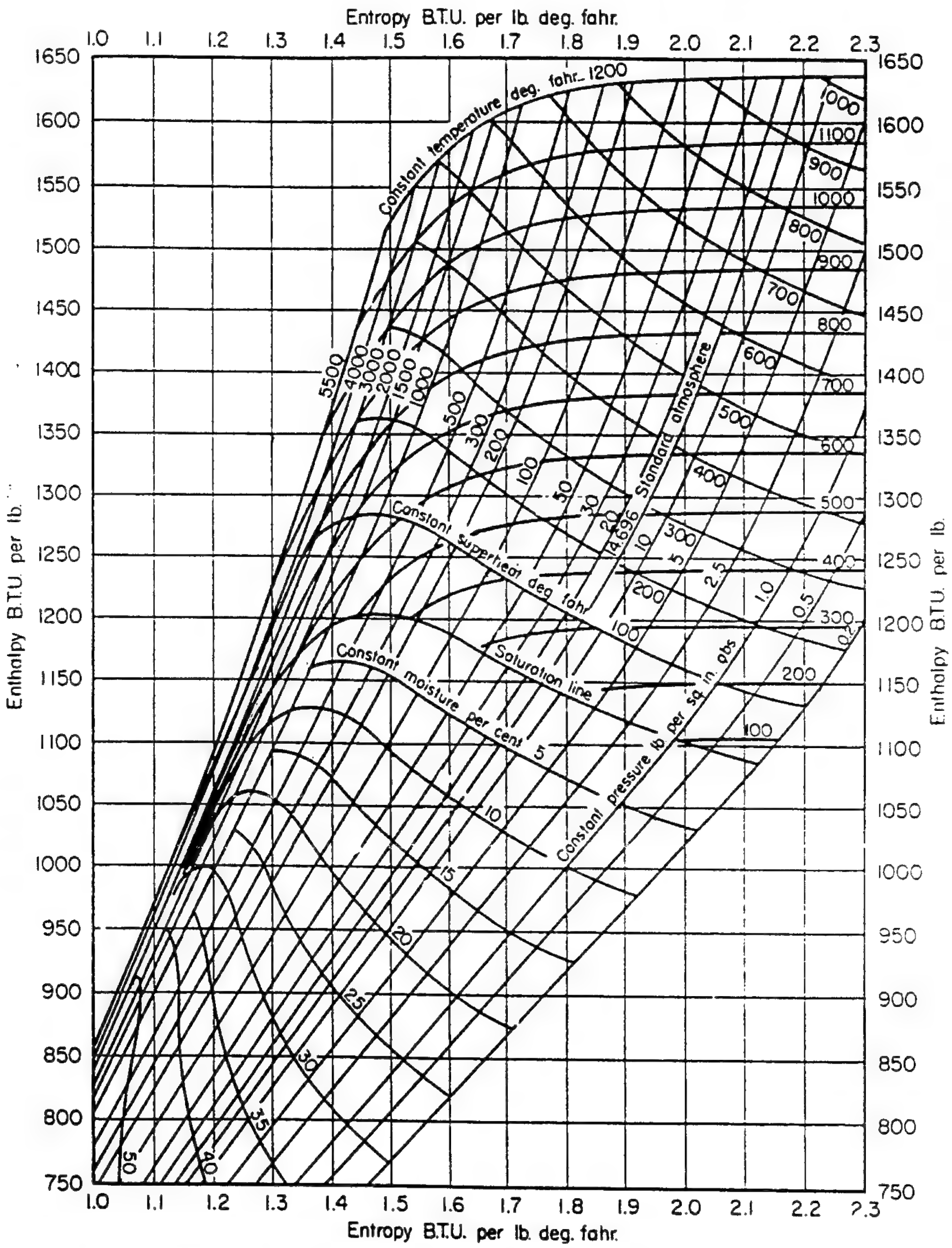


Fig. 22 Enthalpy-entropy (Mollier) chart for steam. *(From "Steam, Its Generation and Use," The Babcock & Wilcox Co., 1963.)*

SCHULLER

Thermo-12® Gold

Pipe and Block Insulation

Heat Transfer Tables

Nominal Pipe Size 18" Metal Jacket

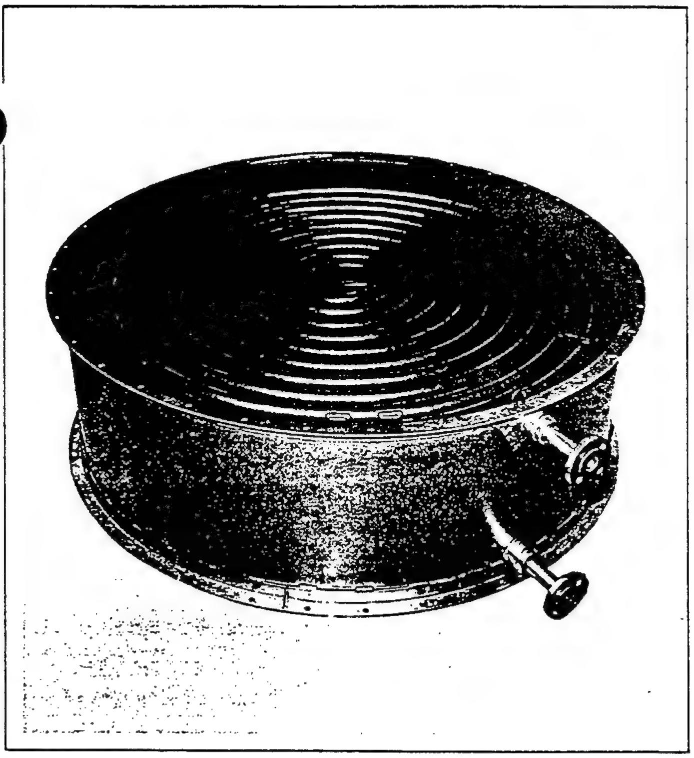
Insulation Thickness (inches)	Pipe Operating Temperature (°F)															
	200		300		400		500		600		800		1000		1200	
	HL*	ST*	HL	ST	HL	ST	HL	ST	HL	ST	HL	ST	HL	ST	HL	ST
Bare	1070	200	2442	300	4309	400	6783	500	9997	600	19265	800	33526	1000	54455	1200
1	157	122	306	153	469	183	651	213	854	245	1345	313	1978	390	2792	476
1½	123	114	236	137	360	161	497	185	650	209	1018	263	1490	325	2094	394
2	100	107	192	127	291	146	401	165	523	185	814	229	1188	280	1666	338
2½	85	103	163	120	246	136	338	152	440	169	685	207	997	250	1395	300
3	75	100	142	114	215	128	294	143	383	157	594	190	864	228	1208	271
3½	67	98	127	110	191	123	262	135	341	148	528	177	767	210	1071	249
4	59	96	113	106	170	117	232	128	302	139	467	165	677	194	945	228
4½	56	95	106	105	160	115	218	125	283	135	438	159	635	186	886	218
5	52	93	98	102	148	111	202	121	262	130	405	152	587	176	818	206
5½	48	92	91	100	137	109	187	117	242	126	375	145	542	168	756	194
6	45	91	86	99	129	106	176	114	228	122	352	140	509	161	709	186
6½	43	90	81	97	122	105	166	112	215	119	332	136	481	156	669	178
7	41	90	77	96	115	103	158	110	204	117	315	132	456	151	635	172
7½	39	89	73	95	110	101	150	108	195	114	300	129	434	146	605	166
8	37	88	70	94	105	100	144	106	186	112	287	126	415	142	578	161
8½	36	88	67	94	101	99	138	105	179	111	275	124	398	139	554	157
9	34	88	65	93	97	98	133	103	172	109	265	121	383	136	533	153
9½	33	87	63	92	94	97	128	102	166	107	256	119	369	133	514	149
10	32	87	61	92	91	96	124	101	160	106	247	117	357	130	496	146

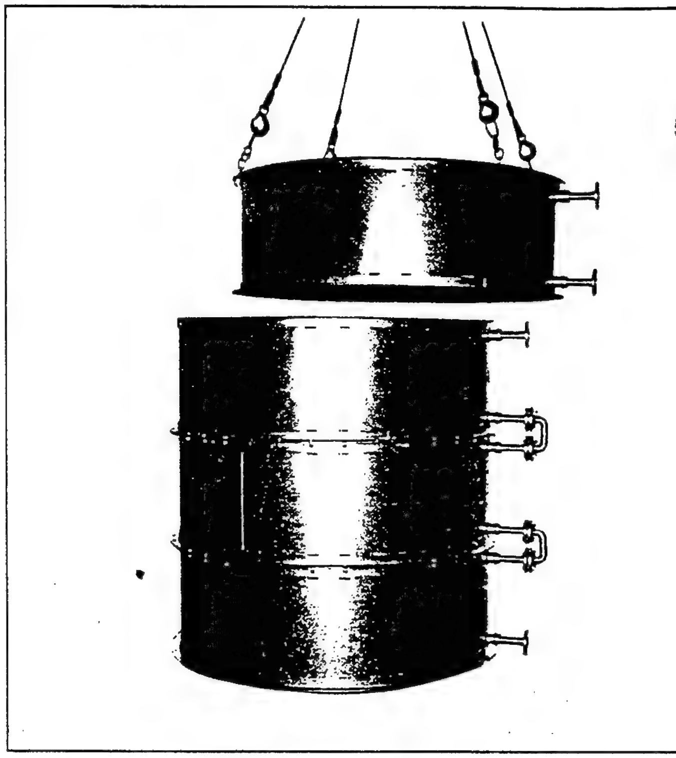
Nominal Pipe Size 18" Dull Surface

Insulation Thickness (inches)	Pipe Operating Temperature (°F)															
	200		300		400		500		600		800		1000		1200	
	HL*	ST*	HL	ST	HL	ST	HL	ST	HL	ST	HL	ST	HL	ST	HL	ST
Bare	1070	200	2442	300	4309	400	6783	500	9997	600	19265	800	33526	1000	54455	1200
1	193	105	366	123	554	141	760	160	991	179	1545	219	2257	264	3172	313
1½	144	98	272	112	410	126	561	140	729	154	1130	186	1644	221	2301	261
2	114	94	215	105	323	116	442	127	573	139	886	164	1285	193	1795	226
2½	95	92	179	101	269	110	367	119	476	128	735	150	1065	174	1485	202
3	82	90	155	97	232	105	317	113	410	121	632	140	915	161	1275	185
3½	73	88	137	95	205	102	280	109	362	116	558	132	807	151	1123	172
4	64	87	120	93	180	98	246	104	318	111	489	124	707	141	984	160
4½	60	87	113	92	169	97	230	102	298	108	458	121	662	136	921	154
5	55	86	104	91	156	95	212	100	274	105	422	117	609	131	847	147
5½	51	85	96	89	143	94	195	98	253	103	389	113	561	126	780	140
6	48	85	90	89	134	92	183	97	237	101	364	110	525	122	730	136
6½	45	84	85	88	127	91	172	95	223	99	343	108	495	119	688	131
7	43	84	80	87	120	91	163	94	211	98	325	106	469	116	651	128
7½	41	84	76	87	114	90	155	93	201	96	309	104	446	113	619	125
8	39	84	73	86	109	89	148	92	192	95	295	103	426	111	591	122
8½	37	83	70	86	104	89	142	91	184	94	283	101	408	109	566	119
9	36	83	67	86	100	88	137	91	177	94	271	100	392	108	544	117
9½	35	83	65	85	97	88	132	90	170	93	261	99	377	106	524	115
10	33	83	62	85	93	87	127	90	164	92	252	98	364	105	506	113

HL: Heat Transfer, BTU/hr. per linear ft.
ST: Surface Temperature, °F.

System





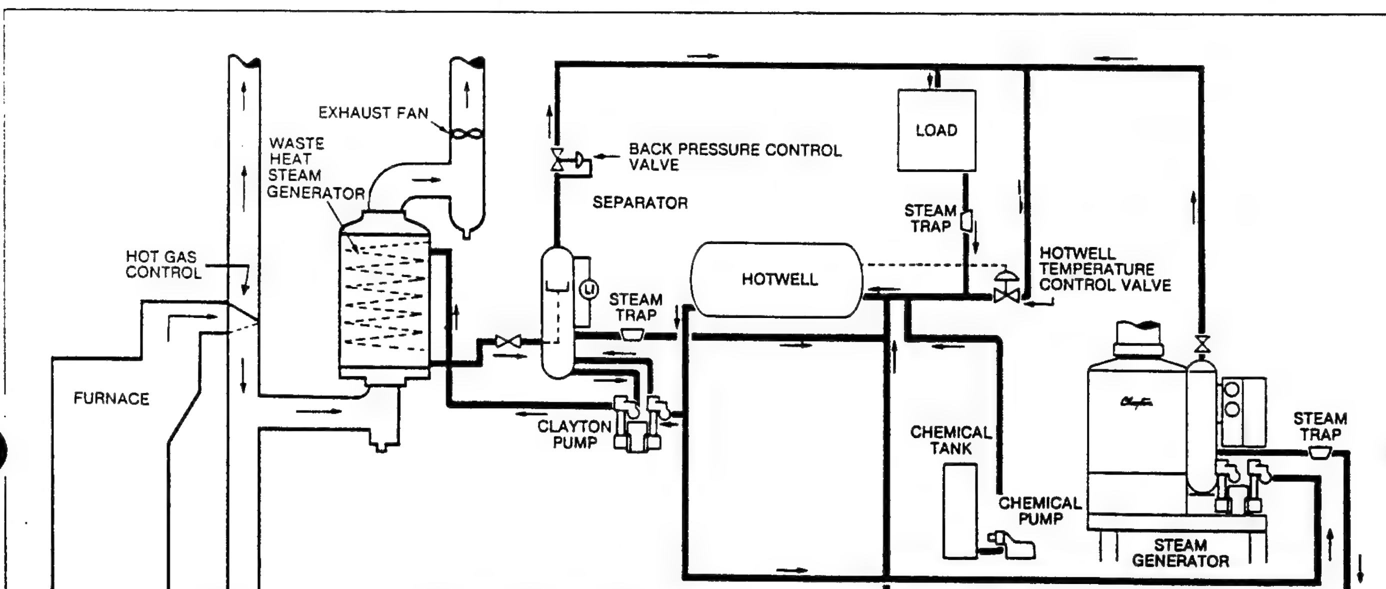
The Clayton Waste Heat Recovery System can be used to generate steam or high temperature hot water. Typical combinations of an exhaust gas or waste heat unit with a direct-fired steam generator are shown below and on the next page. Similar combinations are available for high temperature hot water production.

A principal feature of the Clayton Waste Heat Steam Generator is its unique coil design. The coil tube is wound in a spiral pattern with planned and closely controlled spacing between the turns. This provides the desired area to control the velocities of the combustion gases.

Various sizes of boiler tubing with relatively small internal volumes are used in the coil. This highly efficient heating surface arrangement minimizes size and weight requirements. Several sizes of coils are available in standard production.

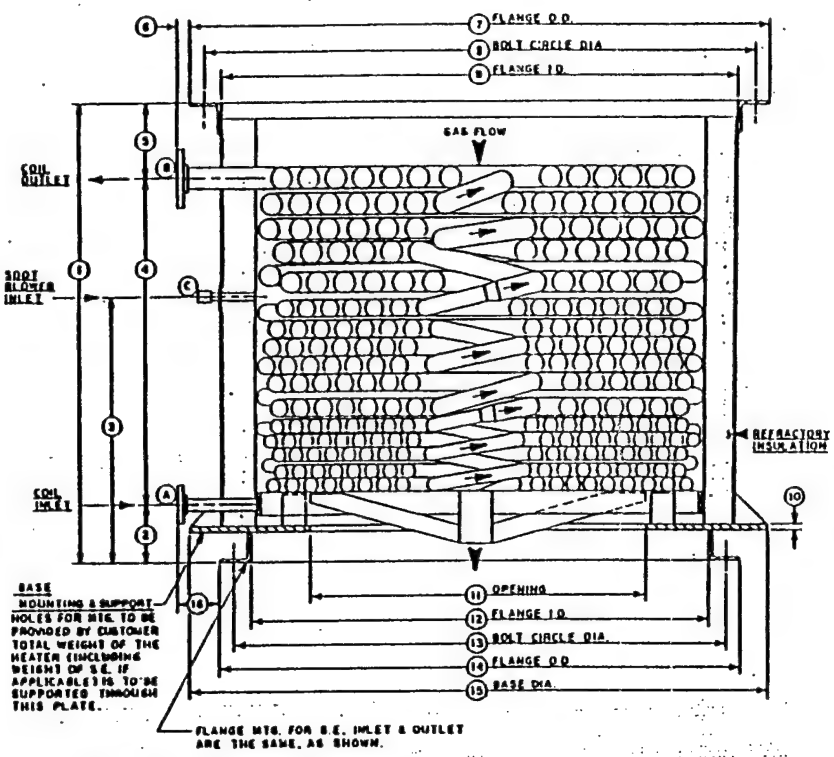
The Exhaust Gas Steam Generator has a somewhat different construction. Its heating section may differ in diameter, quantity of coils per section and flue gas area. A set of four or six coils and pipe sizes from 1″ to 2″ are used. Combinations are put together to produce the required steam output. This provides flexibility in matching exhaust gas rates with standard size sections.

In applications where gas temperatures are below 427 °C (800 °F)—typical of marine diesels—the steam or hot water flow in any section of the unit can be bypassed if one of the spiral coils is damaged. Although the steam or hot water output would be reduced after bypass, complete shutdown is not necessary.

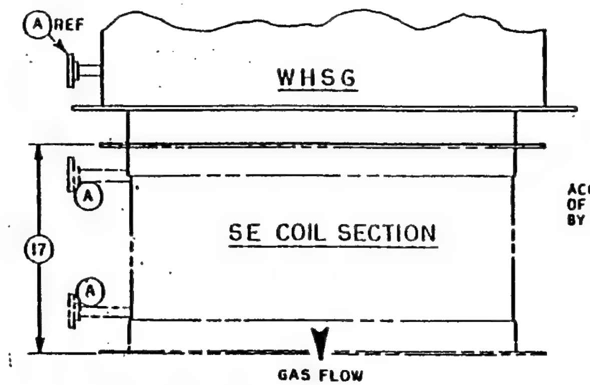


Waste Heat Steam Generator with Direct-Fired Steam Generator

R-10951



NOTE:
COIL TUBING MAT'L. IS ASME SA 178 GRADE A.
ALL OTHER IS MILD STEEL.



ACCESS FOR REMOVAL OR SERVICE OF THE S.E. MUST BE PROVIDED BY CUSTOMER.

LEGEND	MODEL E-200 WHSG	MODEL E-302 WHSG	MODEL E-500 WHSG
(A)	3/4", 300# FLANGE	1-1/4, 300# FLANGE	1-1/4, 300# FLANGE
(B)	2", 300# FLANGE	2-1/2, 300# FLANGE	2-1/2, 300# FLANGE
(C)	1"(F)N.P.T.	1"(F)N.P.T.	1"(F)N.P.T.
(1)	30.38	50.94	60.00
(2)	6.50	6.50	7.75
(3)	25.12	20.56	34.94
(4)	25.06	37.18	43.06
(5)	6.75	7.25	8.19
(6)	1.50	1.50	1.94
(7)	53.25	63.00 O.D.	72.75 O.D.
(8)	50.625 CD. 9/16 DIA., 24 HOLES	60.38 BCD. 9/16 DIA., 24 HOLES	61.12 BCD. 9/16 DIA., 24 HOLES
(9)	47.25	57.00 I.D.	64.75
(10)	1/2" THICK	1/2" THICK	3/4" THICK
(11)	22.00	42.00 I.D.	42.00
(12)	38.31	48.12 I.D.	56.88 I.D.
(13)	49.89 BCD. 9/16 DIA., 24 HOLES	51.50 BCD. 9/16 DIA., 24 HOLES	63.25 BCD. 9/16 DIA., 24 HOLES
(14)	45.31	54.12 O.D.	66.88 O.D.
(15)	53.25	65.00 O.D.	73.00 O.D.
(16)	6.50	5.94	5.50
WEIGHT DRY	2618 LB	4536 LB.	7639 LB
WEIGHT MAX WET	3015 LB	5494 LB.	9290 LB
VOLUME	47.3 GAL	115 GAL.	198.2 GAL
HEATING SURFACE	255.3 FT²	488 FT²	771.4 FT²
ECONOMIZER SECTION			
(17)	16.50	25.25	27.25
WEIGHT DRY	680 LB	1200 LB	1766 LB
WEIGHT MAX WET	812 LB	1533 LB	2320 LB
VOLUME	19.5 GAL	40 GAL.	86.6 GAL.
HEATING SURFACE	125 FT²	202 FT²	283 FT²

LTR	REVISION	BY	DATE	CHK
C	ADDED MDL. 200	JC	5 17 85	✓

ITEM | DESCRIPTION OF PART | STOCK NO. | REQ.
BILL OF MATERIAL

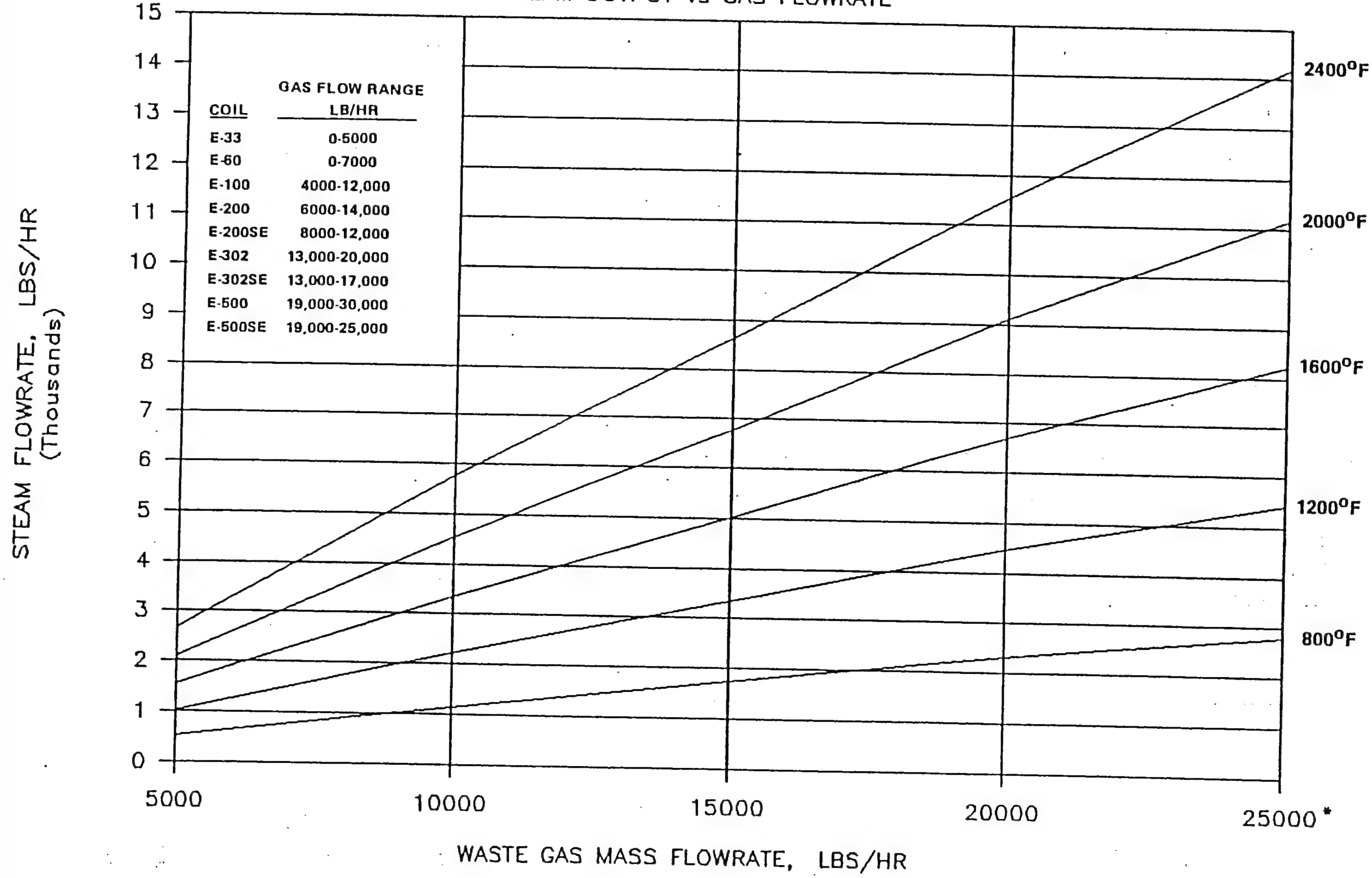
CLAYTON MFG. CO. EL MONTE, CALIF. 9173-

PLAN DIMENSIONAL
WASTE HEAT STEAM GENERATOR
DOWNFLOW

MODEL E-200, 302 & 500
DO NOT SCALE PRINT
C R-10951

CLAYTON WHSG PERFORMANCE

STEAM OUTPUT vs GAS FLOWRATE



S/HR.

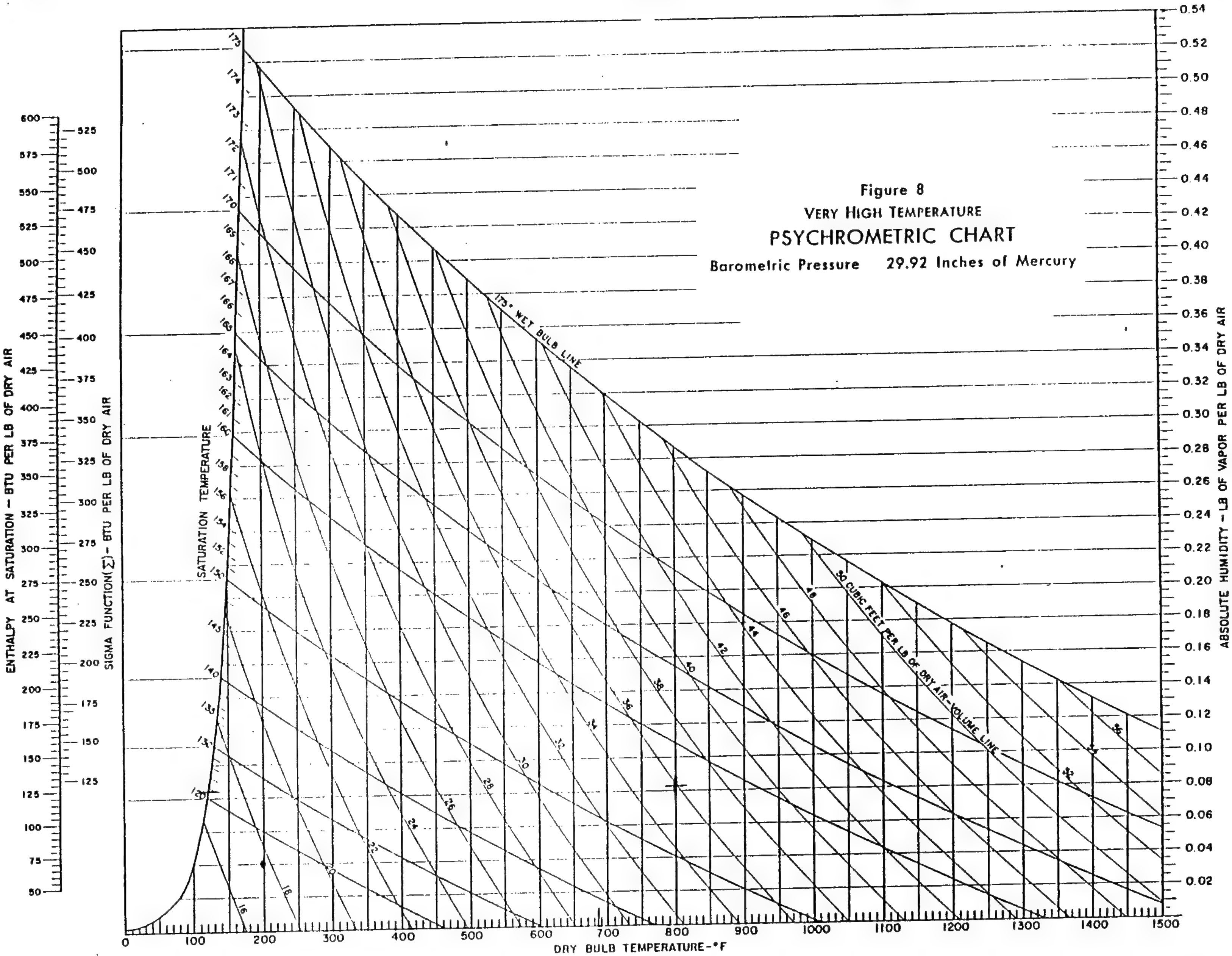


Figure 8
VERY HIGH TEMPERATURE
PSYCHROMETRIC CHART
Barometric Pressure 29.92 Inches of Mercury

INTERNAL COMBUSTION ENGINES - OBERT

TABLE II*A*

Approximate Heat-Capacity Equations*

Gas	Molecular Weight	Specific Heat at Constant Pressure (c_p), Btu lb_m^{-1} R^{-1} T = Rankine Degrees	Range R	Maximum Deviation from Experimental Data (per cent)
N_2	28.02	$0.227+0.0000292T$	720–1900	Less than 1
H_2O ...	18.016	$0.433+0.0000166T$	720–1900	....
CO_2	44.00	$0.186+0.0000625T$	720–1900	Less than 3
CO.....	28.00	$0.226+0.0000321T$	720–1900	Less than 1
H_2	2.016	$3.35\ +0.000114T$	720–1900	Less than 1
CH_4	16.03	$0.208+0.000561T$	720–1900	....
O_2......	32.00	$0.200+0.0000353T$	720–1900	Less than 1
Air.....	28.96	$0.220+0.0000306T$	720–1900	Less than 1
C_8H_{18} ...	114.14	$0.105+0.000486T$	720–1900	....

* E. S. Taylor, W. A. Leary, and J. R. Diver, *Effect of Fuel-Air Ratio, Inlet Temperature and Exhaust Pressure on Detonation*, NACA Report No. 699 (1940).

TABLE II*B*

Heat-Capacity Equations*

Gas or Vapor	Equation c_p in Btu $mole^{-1}$ R^{-1}	Range R	Maximum Error (per cent)
O_2.....	$c_p=11.515-\frac{172}{\sqrt{T}}+\frac{1530}{T}$	540–5000	1.1
	$=11.515-\frac{172}{\sqrt{T}}+\frac{1530}{T}+\frac{0.05}{1000}(T-4000)$	5000–9000	0.3
N_2....	$c_p=9.47-\frac{3.47\times10^3}{T}+\frac{1.16\times10^6}{T^2}$	540–9000	1.7
CO....	$c_p=9.46-\frac{3.29\times10^3}{T}+\frac{1.07\times10^6}{T^2}$	540–9000	1.1
H_2....	$c_p=5.76+\frac{0.578}{1000}T+\frac{20}{\sqrt{T}}$	540–4000	0.8
	$=5.76+\frac{0.578}{1000}T+\frac{20}{\sqrt{T}}-\frac{0.33}{1000}(T-4000)$	4000–9000	1.4
H_2O...	$c_p=19.86-\frac{597}{\sqrt{T}}+\frac{7500}{T}$	540–5400	1.8
CO_2...	$c_p=16.2-\frac{6.53\times10^3}{T}+\frac{1.41\times10^6}{T^2}$	540–6300	0.8
CH_4...	$c_p=4.52+0.00737T$	540–1500	1.2
C_2H_4..	$c_p=4.23+0.01177T$	350–1100	1.5
C_2H_6..	$c_p=4.01+0.01636T$	400–1100	1.5
C_8H_{18}..	$c_p=7.92+0.0601T$	400–1100	Est. 4
$C_{12}H_{26}$.	$c_p=8.68+0.0889T$	400–1100	Est. 4

* R. L. Sweigert and M. W. Beardsley, *Empirical Specific Heat Equations Based upon Spectroscopic Data*, Georgia School of Technology Bulletin, Vol. 1, No. 3 (June, 1938).

TA

GAS-CON

Gas	Chemical Formula	Molec. Weig. M
Acetylene..........	C_2H_2	26.0
Air		28.9
Ammonia..........	NH_3	17.0
Argon............	A	39.9
Butane...........	C_4H_{10}	58.0
Carbon dioxide.....	CO_2	44.0
Carbon monoxide...	CO	28.0
Dodecane..........	$C_{12}H_{26}$	170.3
Ethane............	C_2H_6	30.0
Ethylene..........	C_2H_4	28.0
Helium............	He	4.0
Hydrogen..........	H_2	2.01
Methane...........	CH_4	16.03
Nitrogen..........	N_2	28.02
Octane............	C_8H_{18}	114.14
Oxygen............	O_2	32.00
Propane...........	C_3H_8	44.06
Sulphur dioxide....	SO_2	64.07
Water vapor........	H_2O	18.01

MARK'S HANDBOOK

Specific Gravity and Density of Water at Atmospheric Pressure
(Weights are in vacuo)

Temp, °C	Specific gravity	Density, lb/ft³	Density, kg/m³	Temp, °C	Specific gravity	Density, lb/ft³	Density, kg/m³
0	0.99987	62.4183	999.845	40	0.99224	61.9428	992.228
2	0.99997	62.4246	999.946	42	0.99147	61.894	991.447
4	1.00000	62.4266	999.955	44	0.99066	61.844	990.647
6	0.99997	62.4246	999.946	46	0.98982	61.791	989.797
8	0.99988	62.4189	999.854	48	0.98896	61.737	988.931
10	0.99973	62.4096	999.706	50	0.98807	61.682	988.050
12	0.99952	62.3969	999.502	52	0.98715	61.624	987.121
14	0.99927	62.3811	999.272	54	0.98621	61.566	986.192
16	0.99897	62.3623	998.948	56	0.98524	61.505	985.215
18	0.99862	62.3407	998.602	58	0.98425	61.443	984.222
20	0.99823	62.3164	998.213	60	0.98324	61.380	983.213
22	0.99780	62.2894	997.780	62	0.98220	61.315	982.172
24	0.99732	62.2598	997.304	64	0.98113	61.249	981.113
26	0.99681	62.2278	996.793	66	0.98005	61.181	980.025
28	0.99626	62.1934	996.242	68	0.97894	61.112	978.920
30	0.99567	62.1568	995.656	70	0.97781	61.041	977.783
32	0.99505	62.1179	995.033	72	0.97666	60.970	976.645
34	0.99440	62.0770	994.378	74	0.97548	60.896	975.460
36	0.99371	62.0341	993.691	76	0.97428	60.821	974.259
38	0.99299	61.9893	992.973	78	0.97307	60.745	973.041

PHYSICAL DATA

Average Composition of Air between Sea Level and 90 km Altitude and Dry

Element	Formula	% by vol.	% by mass	Molecular weight
Nitrogen	N_2	78.084	75.55	28.0134
Oxygen	O_2	20.948	23.15	31.9988
Argon	Ar	0.934	1.325	39.948
Carbon dioxide	CO_2	0.0314	0.0477	44.00995
Neon	Ne	0.00182	0.00127	20.183
Helium	He	0.00052	0.000072	4.0026
Krypton	Kr	0.000114	0.000409	83.80
Methane	CH_4	0.0002	0.000111	16.043

From 0.0 to 0.00005 percent by volume of 9 other gases.
Average composite molecular weight of air 28.9644
Data from "U.S. Standard Atmosphere, 1962," Government Printing Office.

Volume of Water as a Function of Pressure and Temperature
(From "International Critical Tables")

Temp, °F (°C)	Pressure in atmospheres: 0	500	1,000	2,000	3,000	4,000	5,000		
32(0)	1.0000	0.9769	0.9566	0.9223	0.8954	0.8739	0.8565	0.8361	
68(20)	1.0016	0.9804	0.9619	0.9312	0.9065	0.8855	0.8675	0.8444	0.8244
122(50)	1.0128	0.9915	0.9732	0.9428	0.9183	0.8974	0.8792	0.8562	0.8369
176(80)	1.0287	1.0071	0.9884	0.9568	0.9315	0.9097	0.8913	0.8679	0.8481

TABLE 136—PROPERTIES OF LIQUIDS

Liquid (at 68°F & 29.92 "Hg or as noted) (100% or % in H_2O as noted)	Formula	Spec. Grav. SG (H_2O = 1)	Spec. Heat c_p (Btu/lb-°F)	Latent Heat λ_v (Btu/lb)	Vapor Press. e_{sat} ("Hg)	Abs. Visc. μ (cp)	Therm. Cond. k @ 54°F (Btu/hr-ft-°F)
Acetic acid	$C_2H_4O_2$	1.049	.468	174	.461	1.22	.099
Acetone	C_3H_6O	.791	.528	237	7.28	.331	.102
Ammonia	NH_3	.618	1.13	518	253	.266	.29
Amyl acetate	$C_7H_{14}O_2$	.871	.459			.806	.073
Aniline	$C_6H_5NH_2$	1.022	.495	187	.002	4.47	.099
Benzene	C_6H_6	.879	.406	188	3.01	.647	.081
Brine—25%	$CaCl_2$	1.228	.687			2.67	.318
Brine—25%	NaCl	1.189	.814			2.02	.265
Butane	C_4H_{10}	.579	.550	158	61.5	.187	.076
Carbon dioxide	CO_2	1.101	.92	63.1	1690	.071	
Carbon disulfide	CS_2	1.263	.240	157	11.60	.376	.083
Carbon tetrachloride	CCl_4	1.594	.201	93.8	3.58	.958	.061
Chloroform	$CHCl_3$	1.489	.234	113	6.27	.563	.070
Ethyl Acetate	$C_4H_8O_2$	.901	.459	183	2.87	.455	.084
Ethyl Alcohol	C_2H_6O	.789	.622	368	1.73	1.19	.101
Ethyl Alcohol—40%	C_2H_6O	.935	.920			1.25	.224
Ethyl Ether	$C_4H_{10}O$	.708	.503	151	17.4	.245	.073
Ethylene glycol	$C_2H_6O_2$	1.115	.57	344	.002	20.9	.167
Ethylene glycol—50%	—	1.067	.70		.40	4.1	.242
Freon 11—12.87 psia	$CFCl_3$	1.490	.214	78.9	27.3	.46	.064
Freon 12—82.28 psia	CF_2Cl_2	1.331	.253	60.6	153	.27	.052
Freon 22—133 psia	CHF_2Cl	1.215	.298	81.0	279	.24	.062
Gasoline	—	.687	.70			.35	
Glycerol	$C_3H_8O_3$	1.261	.573			1069	.162
Heptane	C_7H_{16}	.684	.508	157	1.30	.416	.082
Hexane	C_6H_{14}	.659	.537	157	4.96	.326	.088
Hydrochloric acid—40%	HCl	1.198	.60	178			.254
Kerosene	—	.82	.50			1.8	.085
Methyl acetate	$C_3H_6O_2$	.933	.468	190	6.68	.388	.093
Methyl alcohol	CH_4O	.792	.610	499	3.78	.593	.120
Methyl chloride	CH_3Cl	.92	.385	172	144	.183	.089
Milk	—	1.03	.93				
Nitric acid	HNO_3	1.502		206		1.77	
Octane	C_8H_{18}	.703	.523	156	.417	.542	.091
Oil, draft gage	—	.834					
Oil, linseed	—	.941	.53			33	
Oil, lube. (med.)	—	.91	.45			200	.080
Oil, olive	—	.92	.33			84	.109
Oil, vegetable	—	.92	.434			40.6	
Pentane	C_5H_{12}	.626	.527	158		.240	.069
Phenol	C_6H_6O	1.071	.561		.001	12.7	
Propane	C_3H_8	.585	.576	150	258	.14	.075
Sulfur dioxide	SO_2	1.434	.35	151	96.5	.27	.115
Sulfuric acid—98%	H_2SO_4	1.836	.336	202		23.0	.205
Toluene	C_7H_8	.866	.407	178	.870	.590	.074
Turpentine	—	.867	.472	133	.17	1.49	.063
Water, 39.2°F (4°C)	H_2O	1.000	1.005	1069	.240	1.567	.325
Water, 59°F (15°C)	H_2O	.999	1.000	1058	.504	1.140	.339
Water, 68.7°F (20.2°C)	H_2O	.998	.998	1054	.707	1.000	.346
Water, 70°F (21.1°C)	H_2O	.998	.998	1053	.739	.978	.347
Water, 212°F (100°C)	H_2O	.958	1.006	970	29.92	.284	.393
Water, heavy	D_2O	1.108	1.018	894			
Water, sea	—	1.025	.94			1.03	.349

Adapted from the data of N. A. Lange, "Handbook of Chemistry," Handbook Publishers, Inc., Sandusky, Ohio, 1952. Refer to manufacturers' data for exact properties.

TABLE 137—PROPERTIES OF SOLIDS

Solid	Density δ (lb/ft³)	Specific Heat c_p (Btu/lb-°F)	Thermal Conductivity k (Btu-in./hr-ft²-°F)
Asbestos	153	.20	1.7
Asbestos—cement board	120	—	4.0
Ashes	43	.20	0.5
Asphalt	82	—	5.2
Bakelite	86	.33	—
Borax	109	.38	—
Brick, common	120	.22	5.0
Brick, face	130	.22	9.0
Calcium carbonate	177	.19	14.4
Calcium chloride	134	.16	—
Carborundum	195	.16	1.5
Celluloid	87	.36	1.4
Cellulose	94	.37	—
Cement, loose	94	.20	2.1
Cement, mortar	116	.20	5.0
Chalk	142	.21	5.8
Charcoal, hardwood	34	.20	—
Cinders, loose	43	.18	—
Clay, dry	63	.22	—
Clay, moist	110	.55	—
Coal, anth., solid	98	.31	—
Coal, bitum., solid	85	.30	—
Coke, solid	75	.20	—
Concrete, cinder	97	.18	3.5
Concrete, stone	140	.19	12.5
Cork	15	.48	0.4
Corkboard	8	—	0.3
Cotton	5	.32	0.4
Dry Ice	97	.12	—
Earth, moist	78	.44	12.0
Ebonite	72	.35	1.2
Fats	58	.46	—
Feldspar	160	.20	16.2
Flannel	—	—	0.7
Glass, crown	160	.16	5.5
Glass, flint	215	.13	4.1
Glass, pyrex	140	.20	7.5
Granite	165	.19	12.5
Graphite	99	.20	306
Gypsum, compressed	152	.26	9.0
Gypsum board	50	—	1.4
Hay, baled	20	.32	—

JOHN A. DEAN

LANGE'S HANDBOOK OF CHEMISTRY

14^{th} EDITION

McGRAW-HILL

TABLE 6.3 Enthalpies and Gibbs Energies of Formation, Entropies, and Heat Capacities of the Elements and Inorganic Compounds (*Continued*)

Substance	State	$\Delta Hf°$, $kJ \cdot mol^{-1}$	$\Delta Gf°$, $kJ \cdot mol^{-1}$	$S°$, $J \cdot deg^{-1} \cdot mol^{-1}$	C_p, $J \cdot deg^{-1} \cdot mol^{-1}$
Nb_2O_5	c	−1 899.5(42)	−1 765.8	137.3(13)	[illegible]
$NbOCl_3$	c	−879.5	−782	159	[illegible]
Nitrogen					
N_2	g	0	0	191.61(2)	[illegible]
NF_3	g	−132.1(11)	−90.6	260.8(2)	[illegible]
N_2F_2 *cis*	g	67	109	259.8	[illegible]
trans	g	81.2	120.5	262.6	[illegible]
N_2H_4 hydrazine	lq	50.6(11)	150.1	121.5(4)	[illegible]
$N_2^2H_4$ hydrazine-d_4	g	81.6	150.9	248.86	[illegible]
$N_2H_5^+$ std. state	aq	−7.5	82.4	151	[illegible]
N_2H_5Br	c	−155.6			
std. state	aq	−128.9	−21.8	233.1	[illegible]
N_2H_5Cl	c	−197.1			
std. state	aq	−174.9	−49.0	207.1	[illegible]
$N_2H_5Cl \cdot HCl$	c	−367.4			
N_2H_5OH	lq	−242.7			
undissoc; ss	aq	−251.50	−109.2	207.9	[illegible]
$N_2H_5NO_3$	c	−251.58			
std. state	aq	−215.10	−28.91	297	
$(N_2H_5)_2SO_4$	c	−959.0			
std. state	aq	−924.7	−579.9	322	−151
NO	g	90.29(17)	86.60	210.76	[illegible]
NOBr	g	82.13	82.42	273.42	[illegible]
NOCl	g	51.71(42)	66.10	261.68(17)	[illegible]
NOF	g	−65.7(17)	−50.3	248.02	[illegible]
NOF_3	g	−163	−96	278.40	[illegible]
NO_2	g	33.1(8)	51.3	240.03(13)	[illegible]
NO_2Cl	g	12.1(17)	54	272.19	[illegible]
NO_2F	g	−109.(21)	−66	250.2	[illegible]
NO_3	g	69.41	114.35	252.5	[illegible]
N_2O	g	82.4(4)	104.2	220.0	[illegible]
N_2O_2	g	170.37	202.88	287.52	[illegible]
$N_2O_2^{2-}$ hyponitrite	aq	−17.2	138.9	27.6	
N_2O_3	g	82.8(8)	139.7	308.5(21)	[illegible]
N_2O_4	lq	−19.56	97.52	209.20	[illegible]
	g	9.08	97.79	304.38	[illegible]
N_2O_5	g	11.3(18)	118.0	346.5(42)	[illegible]
Osmium					
Os	c	0	0	32.6	[illegible]
$OsCl_3$	c	−190.4	−121	130	
$OsCl_4$	c	−254.8	−159	155	
OsO_4	c	−394.1	−305.0	143.9	
Oxygen					
O_2	g	0	0	205.147(35)	[illegible]
O_3	g	142.7(17)	163.2	238.9	[illegible]
OF_2	g	24.5(16)	41.8	247.5(4)	[illegible]
O_2F_2	g	19.79	61.42	268.11	[illegible]
Palladium					
Pd	c	0	0	37.91	[illegible]

TABLE I

Combustion Constants

No.	Substance	Formula	Molecular Weight	Lb per Cu Ft	Cu Ft per Lb	Sp Gr Air 1.0000	Heat of Combustion: Btu per Cu Ft Gross (High)	Btu per Cu Ft Net (Low)	Btu per Lb Gross (High)	Btu per Lb Net (Low)	For 100% Total Air, Moles per mole of Combustible or Cu Ft per Cu Ft of Combustible: Required for Combustion O_2	N_2	Air	Flue Products CO_2	H_2O	N_2	For 100% Total Air, Lb per Lb of Combustible: Required for Combustion O_2	N_2	Air	Flue Products CO_2	H_2O	N_2
1	Carbon*	C	12.01	.....	......	......	...	...	14,093	14,093	1.0	3.76	4.76	1.0	...	3.76	2.66	8.86	11.53	3.66	...	8.86
2	Hydrogen	H_2	2.016	0.0053	187.723	0.0696	325	275	61,100	51,623	0.5	1.88	2.38	...	1.0	1.88	7.94	26.41	34.34	....	8.94	26.41
3	Oxygen	O_2	32.000	0.0846	11.819	1.1053	...	...	......	.....	...	....	....	...	...	....	....	....	....	....	...	....
4	Nitrogen (atm)	N_2	28.016	0.0744	13.443	0.9718	...	...	......	.....	...	....	....	...	...	....	....	....	....	....	...	....
5	Carbon monoxide	CO	28.01	0.0740	13.506	0.9672	322	322	4,347	4,347	0.5	1.88	2.38	1.0	...	1.88	0.57	1.90	2.47	1.57	...	1.90
6	Carbon dioxide	CO_2	44.01	0.1170	8.548	1.5282	...	...	......	.....	...	....	....	...	...	....	....	....	....	....	...	....
	Paraffin series																					
7	Methane	CH_4	16.041	0.0424	23.565	0.5543	1013	913	23,879	21,520	2.0	7.53	9.53	1.0	2.0	7.53	3.99	13.28	17.27	2.74	2.25	13.28
8	Ethane	C_2H_6	30.067	0.0803	12.455	1.0488	1792	1641	22,320	20,432	3.5	13.18	16.68	2.0	3.0	13.18	3.73	12.39	16.12	2.93	1.80	12.39
9	Propane	C_3H_8	44.092	0.1196	8.365	1.5617	2590	2385	21,661	19,944	5.0	18.82	23.82	3.0	4.0	18.82	3.63	12.07	15.70	2.99	1.63	12.07
10	n-Butane	C_4H_{10}	58.118	0.1582	6.321	2.0665	3370	3113	21,308	19,680	6.5	24.47	30.97	4.0	5.0	24.47	3.58	11.91	15.49	3.03	1.55	11.91
11	Isobutane	C_4H_{10}	58.118	0.1582	6.321	2.0665	3363	3105	21,257	19,629	6.5	24.47	30.97	4.0	5.0	24.47	3.58	11.91	15.49	3.03	1.55	11.91
12	n-Pentane	C_5H_{12}	72.144	0.1904	5.252	2.4872	4016	3709	21,091	19,517	8.0	30.11	38.11	5.0	6.0	30.11	3.55	11.81	15.35	3.05	1.50	11.81
13	Isopentane	C_5H_{12}	72.144	0.1904	5.252	2.4872	4008	3716	21,052	19,478	8.0	30.11	38.11	5.0	6.0	30.11	3.55	11.81	15.35	3.05	1.50	11.81
14	Neopentane	C_5H_{12}	72.144	0.1904	5.252	2.4872	3993	3693	20,970	19,396	8.0	30.11	38.11	5.0	6.0	30.11	3.55	11.81	15.35	3.05	1.50	11.81
15	n-Hexane	C_6H_{14}	86.169	0.2274	4.398	2.9704	4762	4412	20,940	19,403	9.5	35.76	45.26	6.0	7.0	35.76	3.53	11.74	15.27	3.06	1.46	11.74
	Olefin series																					
16	Ethylene	C_2H_4	28.051	0.0746	13.412	0.9740	1614	1513	21,644	20,295	3.0	11.29	14.29	2.0	2.0	11.29	3.42	11.39	14.81	3.14	1.29	11.39
17	Propylene	C_3H_6	42.077	0.1110	9.007	1.4504	2336	2186	21,041	19,691	4.5	16.94	21.44	3.0	3.0	16.94	3.42	11.39	14.81	3.14	1.29	11.39
18	n-Butene	C_4H_8	56.102	0.1480	6.756	1.9336	3084	2885	20,840	19,496	6.0	22.59	28.59	4.0	4.0	22.59	3.42	11.39	14.81	3.14	1.29	11.39
19	Isobutene	C_4H_8	56.102	0.1480	6.756	1.9336	3068	2869	20,730	19,382	6.0	22.59	28.59	4.0	4.0	22.59	3.42	11.39	14.81	3.14	1.29	11.39
20	n-Pentene	C_5H_{10}	70.128	0.1852	5.400	2.4190	3836	3586	20,712	19,363	7.5	28.23	35.73	5.0	5.0	28.23	3.42	11.39	14.81	3.14	1.29	11.39
	Aromatic series																					
21	Benzene	C_6H_6	78.107	0.2060	4.852	2.6920	3751	3601	18,210	17,480	7.5	28.23	35.73	6.0	3.0	28.23	3.07	10.22	13.30	3.38	0.69	10.22
22	Toluene	C_7H_8	92.132	0.2431	4.113	3.1760	4484	4284	18,440	17,620	9.0	33.88	42.88	7.0	4.0	33.88	3.13	10.40	13.53	3.34	0.78	10.40
23	Xylene	C_8H_{10}	106.158	0.2803	3.567	3.6618	5230	4980	18,650	17,760	10.5	39.52	50.02	8.0	5.0	39.52	3.17	10.53	13.70	3.32	0.85	10.53
	Miscellaneous gases																					
24	Acetylene	C_2H_2	26.036	0.0697	14.344	0.9107	1499	1448	21,500	20,776	2.5	9.41	11.91	2.0	1.0	9.41	3.07	10.22	13.30	3.38	0.69	10.22
25	Naphthalene	$C_{10}H_8$	128.162	0.3384	2.955	4.4208	5854	5654	17,298	16,708	12.0	45.17	57.17	10.0	4.0	45.17	3.00	9.97	12.96	3.43	0.56	9.97
26	Methyl alcohol	CH_3OH	32.041	0.0846	11.820	1.1052	868	768	10,259	9,078	1.5	5.65	7.15	1.0	2.0	5.65	1.50	4.98	6.48	1.37	1.13	4.98
27	Ethyl alcohol	C_2H_5OH	46.067	0.1216	8.221	1.5890	1600	1451	13,161	11,929	3.0	11.29	14.29	2.0	3.0	11.29	2.08	6.93	9.02	1.92	1.17	6.93
28	Ammonia	NH_3	17.031	0.0456	21.914	0.5961	441	365	9,668	8,001	0.75	2.82	3.57	...	1.5	3.32	1.41	4.69	6.10	....	1.59	5.51
														SO_2						SO_2		
29	Sulfur*	S	32.06	......	......	......	...	...	3,983	3,983	1.0	3.76	4.76	1.0	...	3.76	1.00	3.29	4.29	2.00	...	3.29
30	Hydrogen sulfide	H_2S	34.076	0.0911	10.979	1.1898	647	596	7,100	6,545	1.5	5.65	7.15	1.0	1.0	5.65	1.41	4.69	6.10	1.88	0.53	4.69
31	Sulfur dioxide	SO_2	64.06	0.1733	5.770	2.2640	...	...	......	.....	...	....	....	...	...	....	....	....	....	....	...	....
32	Water vapor	H_2O	18.016	0.0476	21.017	0.6215	...	...	......	.....	...	....	....	...	...	....	....	....	....	....	...	....
33	Air	.....	28.9	0.0766	13.063	1.0000	...	...	......	.....	...	....	....	...	...	....	....	....	....	....	...	....

*Carbon and sulfur are considered as gases for molal calculations only.

Note: This table is reprinted from *Fuel Flue Gases*, 1941 Edition, courtesy of American Gas Association.

All gas volumes corrected to 60 F and 30 in. Hg dry.

Fig. 94-1

PHYSICAL PROPERTIES — Liquids and Misc.

	mol. wt	sp gr 60-70F	sp ht 60F	mp F	bp F	LH	k	Viscosity centipoises				Viscosity SSU			
								4.4C 40F	26.7C 80F	49C 120F	71C 160F	4.4C 40F	26.7C 80F	49C 120F	71C 160F
Acids															
Acetic acid, 100%	60	1.05	.48	62	245	175[1]	.095	1.65	1.18	0.85	0.65				
Acetic acid, 10%		1.01	.96												
Fatty acid — oleic	282	0.89		13	547		.092								
Fatty acid — palmitic	256	0.853	.653	146	520	21.8	.083								
Fatty acid — stearic	284	0.847	.550	157	721	26.4	.078								
Hydrochloric acid 31.5% (muriatic)		1.15	.6	-53				2.5	1.85	1.42	1.1				
Hydrochloric acid 10% (muriatic)		1.05	.75												
Nitric acid, 95%		1.50	.5	-44	187			1.45	1.05	.8	.61				
Nitric acid, 60%		1.37	.64	-9.4				3.4	2.2	1.5	1.05				
Nitric acid, 10%		1.05	.9												
Phenol (carbolic acid)	94	1.07	.56	106	346	16.1		14.5	7.3	3.9	2.1				
Phosphoric acid, 20%		1.11	.85												
Phosphoric acid, 10%		1.05	.93												
Sulfuric acid, 110% (Fuming)			.27	92	342			82.0	41.0	22.0	12.2	280	100	55	
Sulfuric acid, 98%		1.84	.35	28.6	625	219[1]	.15	46.0	23.0	11.5	6.4	118	68	45	37
Sulfuric acid, 60%		1.50	.52	-20	282		.24	8.9	5.8	3.9	2.7				
Sulfuric acid, 20%		1.14	.84	8	218			2.5	1.4	0.8	0.55				
Water solutions															
Brine — calcium chloride, 25%		1.23	.689	-21			.28	4.5	2.1	0.95	0.52				
Brine — sodium chloride, 25%		1.19	.786	-16	221		.24	3.3	2.1	1.3	.92				
Sea water		1.03	.94												
Sodium hydroxide, 50% (caustic soda)		1.53	.78					250.0	77.0	26.0	9.5	950	240	84	46
Sodium hydroxide, 30%		1.33	.84						9.6	4.5	2.5				
Water	18	1.0	1.0	32	212	144	34	1.55	0.86	0.56	0.4				
Food Products*															
Dextrose, corn syrup 40° Baume		1.38			225							170000	11000	1700	430
Dextrose, corn syrup 45° Baume		1.45			237								2×10^6	120000	12000
Fish, fresh, avg.			.76			101									
Fruit, fresh, avg.			.88			120									
Honey			.34			30									
Ice		.9	.5			144									
Ice cream			.70			96									
Lard		.92	.64			22									
Maple syrup			.48			52						10000	450	155	88
Meat, fresh, avg.			.70			90									
Milk, 3.5%		1.03	.90			124									
Molasses, primary A			.6										10000	2600	
Molasses, secondary B													70000	10000	
Molasses, blackstrap (final) C													300000	25000	
Starch		1.53													
Sucrose, 60% sugar syrup		1.29	.74	10	218			156	41.0	14.0	7.0	500	153	68	
Sucrose, 40% sugar syrup		1.18	.66	25	214			12.0	5.0	2.5	1.6				
Sugar, cane & beet		1.66	.3												
Vegetables, fresh, avg.			92			72									
Wines, table and dessert, avg.		1.03	.92	7 to 22		130									
Petroleum Products															
Asphalt, RS-1, MS-1, SS-1, emulsion		1.0	.42						86	34	17		400	160	85
Asphalt, RC-0, MC-0, SC-0, cut back													950	340	150
Asphalt, RC-3, MC-3, SC-3, cut back													40000	7000	1600
Asphalt, RC-5, MC-5, SC-5, cut back													500000	45000	8000
Asphalt, 100-120 penetration		1.0											3500 at 250F		
Asphalt, 40-50 penetration		1.01											8000 at 250F		
Benzene	78	.844	.41	42	176	170[1]	0.087	.8	62	46	0.30				
Gasoline		.6	53			140[1]	0.078	7	55	44	0.35				
No. 1 Fuel Oil (Kerosene)		.811	47			110[1]	0.084	3.3	2.1	1.4	0.95	40	36		
No. 2 Fuel Oil, - PS100		865	44				0.08	4.6	2.6	1.6	1.15	43	36	33	32
No. 3 Fuel Oil, - PS200		.887	.43				0.078	15.0	7.0	4.0	2.9	84	52	41	37
No. 4 Fuel Oil		901	.42				0.075	92.0	24.0	9.6	5.0	480	125	62	42
No. 5 Fuel Oil, - PS300		.937	.41				0.072		390.0	75.0	25.0		1600	370	125
No. 6 Fuel Oil, Bunker C PS400		956	40				0.070		1000.0	155.0	40.0		4500	680	180
Transformer oil, light		898	42				0.075	34.2	12.1	6.3	3.9	170	72	49	40
Transformer oil, medium		.91	42					89.0	28.2	11.9	6.7	463	145	70	50
34° API Mid-continent crude		.855	44				0.08	15	6.5	3.0	2.0	88	51	37	34
28° API gas oil		.887	42				0.078	25	9.0	6.0	4.0	135	59	48	41
Quench and tempering oil		.91													
SAE - 5W (+8 machine lube oil)		.88						110	30	12	7	550	160	74	51
SAE—10W (+10 machine lube oil)								170	50	22	11	1500	265	120	64
SAE—20 (+ 20 machine lube oil)		89						580	98	33	14	2900	500	170	80
SAE—30 (+ 30 machine lube oil)		.89						1200	200	60	25	5000	870	260	110
SAE—40												8500	1400	380	150
SAE—50									400	100	45	23000	3600	720	225
Paraffin, melted		9	69	100-133	660-870	70	0.14								
Toluene	92	.862	.42	-139	231	157[1]	0.084	.75	.57	.45	.36				
Miscellaneous															
Acetone, 100%	58	.789	.514	-137	133	225[1]	.096	0.4	0.32	0.26	0.21				
Alcohol, ethyl, 95%		.81	.6			370[1]	.11	2.0	1.3	.8	0.53				
Alcohol, methyl, 90%		.82	.65				.13	1.0	0.73	.53	0.43				
Ammonia, 100%	17	.77	1.1	-106	-27	589[1]	.29	0.14	0.1	0.08	0.06				
Ammonia, 26%		.905	1.0				.26	1.8	1.2						
Aroclor		1.44	.28		650		0.057	2000	200	32	10	20000	500	95	48
Cotton seed oil		.95	.47				.1								
Creosote	(See coal tars)														
Dowtherm A	166	.995	.63	54	500	123	.08								
Dowtherm C	231	1.10	.35-.65	70-220	600		.08								
Ethylene glycol	62	1.11	.58	9.5	387	346[1]	.153	44.0	19.0	9.0	4.5	185	86	53	39
Glue, 2 parts water, 1 part dry glue		1.09	.89												
Glycerol, 100% (glycerin)	92	1.26	.58	62.5	554	340[1]	.164		490.0	130.0	56.0	25000	3100	700	230
Glycerol, 50%		1.13		-6.5			.24	11.0	5.4	2.8	1.5				
Linseed oil		.93	.44	-5.0	552			72	37	20	11				
Phthalic anhydride	148	1.53	.232	267	544	66									
Soybean oil		.92	.24-.33	3-14					45.0						
Sulfur, melted	32	1.8		239	832										
Trichloroethylene	166	1.62	215	-99	189	90	.070	.7	0.58	0.46	0.4				
Turpentine, spirits of	136	.86	.42	14	320	184[1]	.074	1.9	1.35	0.95	0.7				
Carbon tetrachloride	154	1.58	.21	-95	170	84[1]	.095	1.3	0.95	0.72	0.56				

[1] This figure is latent heat of vaporization.
*sp ht of food products are for above freezing.
Below freezing the values are approx. 60% of those given.

mol wt — molecular weight
sp ht — Btu/lb F
mp — Melting point, F

bp — Boiling point, F
LH — Latent heat of fusion, Btu/lb
k — Thermal conductivity, Btu/sq ft hr F/ft

Table 3-37. HEAT OF DILUTION OF ACIDS*

VIVIAN B. PARKER

ΔH_{diln}, the integral heat of dilution, is the change in enthalpy, per mole of solute, when a solution of concentration m_1 is diluted to a final finite concentration m_2. When the dilution is carried out by addition of an infinite amount of solvent, so the final solution is infinitely dilute, the enthalpy change is the integral heat of dilution to infinite dilution. Since Φ_L, the relative apparent molal enthalpy, is equal to and opposite in sign to this, only Φ_L is referred to here.

Φ_L, cal/mol, at 25 deg C (298.15 K)[a]

n	m	HF	HCl	$HClO_4$	HBr	HI	HNO_3	CH_2O_2	$C_2H_4O_2$
∞	0.00	0	0	0	0	0	0	0	0
500,000	.000111	300	5	5	5	5	5	9	40
100,000	.000555	900	10	10	9	9	11	13	50
50,000	.00111	1,300	16	14	13	12	15	20	53
20,000	.00278	1,800	25	22	22	20	23	23	55
10,000	.00555	2,130	34	30	31	29	31	25	58
7,000	.00793	2,250	40	35	37	34	36	26	59
5,000	.01110	2,360	47	40	44	41	42	26	61
4,000	.01388	2,450	54	43	49	46	46	27	62
3,000	.01850	2,550	60	47	56	52	51	28	62
2,000	.02775	2,700	74	54	68	63	59	28	63
1,500	.03700	2,812	85	58	77	71	65	29	64
1,110	.05000	2,927	97	62	89	81	73	29	65
1,000	.05551	2,969	102	62	92	84	76	29	65
900	.0617	2,989	107	63	97	88	78	30	66
800	.0694	3,015	113	64	102	92	81	31	67
700	.0793	3,037	120	65	108	96	84	32	68
600	.0925	3,057	129	65	115	102	88	32	68
555.1	.1000	3,060	133	65	119	105	89	32	69
500	.1110	3,077	140	65	124	108	92	32	70
400	.1388	3,097	156	64	135	116	97	33	72
300	.1850	3,126	176	61	150	125	103	34	76
277.5	.2000	3,129	182	59	155	128	105	35	79
200	.2775	3,142	212	50	176	140	117	36	82
150	.3700	3,148	242	36	197	154	118	39	88
111.0	.5000	3,156	280	18	225	170	119	42	97
100	.5551	3,160	295	+12	235	176	120	44	101
75	.7401	3,167	343	−14	270	194	121	49	113
55.51	1.0000	3,179	405	−48	314	223	121	54	130
50	1.1101	3,184	431	−61	331	234	121	56	147
40	1.3877	3,192	493	−91	379	260	121	60	155
37.00	1.5000	3,194	518	−103	398	269	121	62	162
30	1.8502	3,200	595	−138	455	301	124	65	183
27.75	2.0000	3,203	627	−149	477	315	126	66	192
25	2.2202	3,208	674	−162	510	336	130	67	204
22.20	2.5000	3,211	732	−173	550	365	139	68	218
20	2.7753	3,214	792	−182	590	396	149	69	233
18.50	3.0000	3,216	838	−187	624	427	159	69	245
15.86	3.500	3,221	946	−196	709	503	189	69	268
15	3.7004	3,227	988	−195	743	536	203	69	277
13.88	4.0000	3,234	1,052	−188	796	588	229	69	291
12.33	4.5000	3,246	1,171	−175	887	676	265	69	313
12	4.6255	3,249	1,190	−170	911	700	277	69	318
11.10	5.0000	3,256	1,271	−150	983	764	313	69	333
10	5.5506	3,265	1,396	−117	1,097	855	368	68	353
9.5	5.8427	3,269	1,462	−97	1,156	920	400	68	363
9.251	6.0000	3,272	1,498	−84	1,196	950	418	67	368
9.0	6.1674	3,274	1,535	−72	1,230	980	437	67	373
8.5	6.5301	3,278	1,618	−40	1,313	1,050	480	66	383
8.0	6.9383	3,282	1,710	+4	1,401	1,115	530	65	392
7.929	7.0000	3,283	1,725	11	1,416	1,130	538	65	394

[a]One calorie (thermochemical) equals 4.184 joules.

te, when a solution
n is carried out by
ıe enthalpy change
molal enthalpy, is

CH_2O_2	$C_2H_4O_2$
0	0
9	40
13	50
20	53
23	55
25	58
26	59
26	61
27	62
28	62
28	63
29	64
[illegible]	65
[illegible]	65
[illegible]	66
31	67
32	68
32	68
32	69
32	70
33	72
34	76
35	79
36	82
39	88
42	97
44	101
49	113
54	130
56	147
60	155
62	162
65	183
66	192
67	204
68	218
69	233
69	245
69	268
69	277
69	291
69	313
69	318
69	333
[illegible]	353
[illegible]	363
[illegible]	368
67	373
66	383
65	392
65	394

Table 3-37. HEAT OF DILUTION OF ACIDS *(Continued)*

n	*m*	*HF*	*HCl*	*HClO₄*	*HBr*	*HI*	*HNO₃*	*CH₂O₂*	*C₂H₄O₂*
7.5	7.4008	3,286	1,820	61	1,497	1,210	595	63	402
7.0	7.9295	3,290	1,942	135	1,608	1,325	661	61	411
6.938	8.0000	3,291	1,960	146	1,622	1,340	667	61	412
6.5	8.5394	3,296	2,090	229	1,738	1,450	745	58	420
6.167	9.0000	3,302	2,202	306	1,845	1,570	805	55	426
6.0	9.2510	3,305	2,265	348	1,903	1,630	840	53	429
5.551	10.0000	3,316	2,447	481	2,078	1,820	940	49	436
5.5	10.0920	3,317	2,472	499	2,102	1,850	950	49	437
5.0	11.1012	3,335	2,721	730	2,344	2,100	1,098	43	445
4.5	12.3346	3,362	3,025	1,144	2,655	2,460	1,270	37	453
4.0	13.8765	3,400	3,404	1,574	3,089	2,960	1,495	29	462
3.700	15.0000	3,428	3,680	1,893	3,415	3,350	1,645	26	469
3.5	15.8589	3,450	3,882	2,150	3,668	3,660	1,770	21	473
3.25	17.0788	3,483	4,160	2,460	4,005	4,110	1,920	17	481
3.0	18.5020	3,520	4,460	2,880	4,370	4,630	2,101	13	488
2.775	20.0000	3,557	4,750	3,300	4,760	5,190	2,270	9	496
2.5	22.2024	3,607	5,180	4,000	5,300	6,000	2,520	+4	506
2.0	27.7530	3,712	6,260	5,500	6,650	.....	3,060	−5	528
1.5	37.0040	.....	8,240	.....	8,530	.....	3,770	−13	532
1.0	55.506	.....	10,900	.....	11,670	.....	4,715	+11	518
0.5	111.012	.....	......	.....	......	.....	.....	77	495
0.25	222.02	.....	......	.....	......	.....	.....	129	......

*From: NSRDS—NBS 2, "Thermal Properties of Aqueous Uni-univalent Electrolytes", V.B. Parker, National Bureau of Standards, 1965.

Table 3-38. HEATS OF SOLUTION*

VIVIAN B. PARKER

ΔH_x 25 deg C for Uni-univalent Electrolytes in H_2O[a]

Substance	*State*	$\Delta H°_x$ (cal/mole)
HF	g	−14,700
HCl	g	−17,888
$HClO_4$	l	−21,215
$HClO_4 \cdot H_2O$	c	−7,875
HBr	g	−20,350
HI	g	−19,520
HIO_3	c	2,100
HNO_3	l	−7,954
HCOOH	l	−205
CH_3COOH	l	−360
NH_3	g	−7,290
NH_4Cl	c	3,533
NH_4ClO_4	c	8,000
NH_4Br	c	4,010
NH_4I	c	3,280
NH_4IO_3	c	7,600
NH_4NO_2	c	4,600
NH_4NO_3	c	6,140
$NH_4C_2H_3O_2$	c	−570
NH_4CN	c	4,200
NH_4CNS	c	5,400
CH_3NH_3Cl	c	1,378
$(CH_3)_3NHCl$	c	350
$N(CH_3)_4Cl$	c	975
$N(CH_3)_4Br$	c	5,800
$N(CH_3)_4I$	c	10,055
$AgClO_4$	c	1,760
$AgNO_2$	c	8,830
$AgNO_3$	c	5,400
LiOH	c	−5,632
$LiOH \cdot H_2O$	c	−1,600
LiF	c	1,130
LiCl	c	−8,850
$LiCl \cdot H_2O$	c	−4,560
$LiClO_4$	c	−6,345
$LiClO_4 \cdot 3H_2O$	c	7,795
LiBr	c	−11,670
$LiBr \cdot H_2O$	c	−5,560

Substance	*State*	ΔH_x (cal/mole)
$LiBr \cdot 2H_2O$	c	−2,250
$LiBrO_3$	c	340
LiI	c	−15,130
$LiI \cdot H_2O$	c	−7,090
$LiI \cdot 2H_2O$	c	−3,530
$LiI \cdot 3H_2O$	c	140
$LiNO_2$	c	−2,630
$LiNO_2 \cdot H_2O$	c	1,680
$LiNO_3$	c	−600
NaOH	c	−10,637
$NaOH \cdot H_2O$	c	−5,118
NaF	c	218
NaCl	c	928
$NaClO_2$	c	80
$NaClO_2 \cdot 3H_2O$	c	6,830
$NaClO_3$	c	5,191
$NaClO_4$	c	3,317
$NaClO_4 \cdot H_2O$	c	5,380
NaBr	c	−144
$NaBr \cdot 2H_2O$	c	4,454
$NaBrO_3$	c	6,430
NaI	c	−1,800
$NaI \cdot 2H_2O$	c	3,855
$NaIO_3$	c	4,850
$NaNO_2$	c	3,320
$NaNO_3$	c	4,900
$NaC_2H_3O_2$	c	−4,140
$NaC_2H_3O_2 \cdot 3H_2O$	c	4,700
NaCN	c	290
$NaCN \cdot \frac{1}{2}H_2O$	c	790
$NaCN \cdot 2H_2O$	c	4,440
NaCNO	c	4,590
NaCNS	c	1,632
KOH	c	−13,769
$KOH \cdot H_2O$	c	−3,500
$KOH \cdot 1\frac{1}{2}H_2O$	c	−2,500
KF	c	−4,238
$KF \cdot 2H_2O$	c	1,666

Substance	*State*	ΔH_x (cal/mole)
KCl	c	4,115
$KClO_3$	c	9,890
$KClO_4$	c	12,200
KBr	c	4,750
$KBrO_3$	c	9,830
KI	c	4,860
KIO_3	c	6,630
KNO_2	c	3,190
KNO_3	c	8,340
$KC_2H_3O_2$	c	−3,665
KCN	c	2,800
KCNO	c	4,840
KCNS	c	5,790
$KMnO_4$	c	10,410
RbOH	c	−14,900
$RbOH \cdot H_2O$	c	−4,310
$RbOH \cdot 2H_2O$	c	210
RbF	c	−6,240
$RbF \cdot H_2O$	c	−100
$RbF \cdot 1\frac{1}{2}H_2O$	c	320
RbCl	c	4,130
$RbClO_3$	c	11,410
$RbClO_4$	c	13,560
RbBr	c	5,230
$RbBrO_3$	c	11,700
RbI	c	6,000
$RbNO_3$	c	8,720
CsOH	c	−17,100
$CsOH \cdot H_2O$	c	−4,900
CsF	c	−8,810
$CsF \cdot H_2O$	c	−2,500
$CsF \cdot 1\frac{1}{2}H_2O$	c	−1,300
CsCl	c	4,250
$CsClO_4$	c	13,250
CsBr	c	6,210
$CsBrO_3$	c	12,060
CsI	c	7,970
$CsNO_3$	c	9,560

[a]25 deg C = 298.15 K. One calorie (thermochemical) = 4.184 joules.

*From: NSRDS—NBS 2, "Thermal Properties of Aqueous Uni-univalent Electrolytes", V.B. Parker, National Bureau of Standards, 1965.

MARKS HANDBOOK

cast and their ends cropped; then they are placed in a furnace and heated to a specified temperature. The heated ingot is placed in a press where it is pierced. This hollow cylinder, open at one end, is then descaled and drawn over a mandrel on a horizontal drawbench. The closed end is then burned off, and the hollow forging is chemically descaled. Following this, the forging is straightened, placed in a lathe, and the outer diameter machined to a true dimension. The inside is dressed to remove scale, but no machining is done on the inside.

Code Designations Appropriate ASTM specifications list the physical and chemical properties of materials used in piping systems. The complete compilation of "Steel Piping, Tubing and Fittings" can be purchased from the ASTM, 1916 Race St., Philadelphia, Pa. 19103. The treatment in this section is a brief outline of frequently encountered materials.

Carbon-steel piping is most frequently used as manufactured in accordance with ASTM specifications A106 and A53. The chemical composition of these two materials is identical; both are subjected to physical tests, but those for A106 are more rigorous. For example, the Code for Pressure Piping permits the use of A53 for pressures of 600 lb/in^2 gage (22,137 N/m^2) and less but excludes its use for higher pressures; A106 can be used for pressures not above 2,500 lb/in^2 gage (92,237 N/m^2). A53 and A106 are made in Grades A and B; Grade B has higher strength properties but is less ductile and, for this reason, Grade A is permitted only for cold bending or close coiling. When carbon steel is intended for use in welded construction at temperatures in excess of 775°F (413°C), consideration should be given to the possibility of graphite formation.

Carbon-molybdenum steel piping may be obtained as A204 (electric-fusion-welded), A335 (seamless) or A369 (forged, turned, and bored). This material was developed in past years when steam temperatures were approaching, but not reaching, 1000°F (538°C) under which conditions carbon steel was both unsatisfactory and uneconomical. It has been found that there is a tendency for carbon-molybdenum to show graphitization at temperatures in excess of 800°F (427°C), and its use in welded construction above this value should be with caution.[1]

Chromium-molybdenum steel has been used for temperatures up to 1100°F (593°C). In the small diameters, the material is usually available in the seamless construction; because of the inability of the seamless mills to fabricate large-diameter and heavy-walled pipe, it may be necessary to resort to the more expensive hollow-forged or forged-and-bored piping for higher pressures and temperatures. The material for a high-temperature piping system should be selected after a careful review of technical and economic considerations; the following is intended only as being indicative of recent and current practice. For temperatures up to 950°F (510°C), ½ percent Cr–½ percent Mo (A335, Grade P2) is used; for temperatures 950 to 1000°F (510 to 538°C), 1 percent Cr–½ percent Mo (A335, Grade P12) is used; for temperatures 1000 to 1050°F (538 to 566°C), 1¼ percent Cr–½ percent Mo (A335, Grade P11) may be used; for temperatures 1050 to 1100°F (566 to 593°C), 2¼ percent Cr–1 percent Mo (A335, Grade P22) is frequently used. When there is a combination of high temperatures and erosive action, 5 percent Cr–½ percent Mo (A335, Grade 5) has been found desirable.

[1]Modern steel-making practices have reduced significantly the problem of graphitization. However, in pipe installed in the 1940s and early 1950s, there have been many failures.

Stainless-steel piping is available in a variety of compositions, most popular of which are ASTM A213, Grade TP321 (16 percent Cr–8 percent Ni, stabilized with titanium) and ASTM A213, Grade TP347 (18 percent Cr–8 percent Ni, stabilized with columbium). Either of these two materials may be used up to 1200°F (649°C); particular care must be given to choice of welding rod to avoid brittleness in the welds.

Refer to Tables 1 and 2, respectively, for permissible stress values for piping materials at low and elevated temperatures.

Schedule Designations Many years ago piping was designated as standard, extra-strong, and double extra-strong. There was no provision for thin-walled pipe, and no intervening standard thicknesses between the three schedules, which covered too great a spread to be economical without intermediate weights. Table 3 lists piping as a function of the schedule number which is given, approximately, by the following relationship: Schedule no. = 1,000 × P/SE, where P is operating pressure, lb/in^2 gage, and SE is allowable stress range multiplied by joint efficiency, lb/in^2.

Example. Find the required schedule of ASTM A106 Grade B pipe operating at 1,150 lb/in^2 gage and 600°F.

Table 2 lists SE value as 15,000 lb/in^2. Substituting, 1,000 (1,150/15,000) = 76.6. Use schedule no. 80, tentatively, but check with Eq. (1), below.

Commercial sizes of wrought-iron and steel pipe are known by their nominal inside diameter (ID) from ⅛ (0.3175 cm) to 12 in (30.5 cm). Above 12 in ID, pipe is usually known by its outside diameter (OD). All classes of pipe of a given nominal size have the same OD, the extra thickness for different weights being on the inside.

Thickness of Pipe The following notes, covering power piping systems, have been abstracted from Part 2 of the Code for Power Piping (ANSI B31.1.0-1967).

For inspection purposes, the minimum thickness of pipe wall to be used for piping at different pressures and for temperatures not exceeding those for the various materials listed in Tables 1 and 2 shall be determined by the formula

$$t_m = \frac{PD}{2(SE + Py)} + A \qquad (1)$$

where t_m = minimum pipe-wall thickness, in, allowable on inspection; P = maximum internal service pressure, lb/in^2 gage (plus water-hammer allowance in case of cast-iron conveying liquids); D = OD of pipe, in; SE = maximum allowable stress in material due to internal pressure and joint efficiency, at the design temperature, lb/in^2; values of SE given in Tables 1 and 2 include allowance for joint efficiency; y = a coefficient, values for which are listed in Table 4; A = allowance for threading, mechanical strength, and corrosion, in, with values of A listed in Table 5.

The thickness of cast-iron pipe conveying liquid may be taken from Table 14, using the pressure class next higher than the maximum internal service pressure in pounds per square inch. Where cast-iron pipe is used for steam service, the thickness should be calculated by Eq. (1), using SE values listed in Table 1.

Plain-end pipe includes pipe joined by flared compression couplings, lapped joints, and by welding, i.e., by any method that does not reduce the wall thickness of the pipe at the joint.

Physical and Chemical Properties of Pipes, Tubes, Etc. The design of piping for operation above 750°F (399°C) presents many problems not encountered at lower temperatures.

Table 2. Allowable Stress Values for Temperatures 650 to 1200°F (343.4 to 649 C) *(Continued)*
(ANSI B36.1.0-1967)

ASTM spec. No.	Grade	Nominal composition	Spec. min tensile	Longitudinal joint efficiency factor	P No.[a]	650°	700	750	800	850	900	950	1,00
Automatically welded austenitic steel, A312	TP304H	18Cr-8Ni[g,i,k]	75,000	0.85	8		12,050	12,000	11,900	11,750	11,550	11,400	10,6
	TP304H	18Cr-8Ni[g,j]	75,000	0.85	8		8,900	8,850	8,700	8,650	8,500	8,300	8,0
	TP316H	18Cr-12Ni-Mo[g,i,k]	75,000	0.85	8		13,600	13,450	13,200	12,950	12,600	12,350	11,9
	TP316H	18Cr-12Ni-Mo[g,j]	75,000	0.85	8		9,600	9,350	9,200	9,000	8,750	8,600	8,3
	TP321H	18Cr-10Ni-Ti[g,i,k]	75,000	0.85	8		12,850	12,850	12,850	12,750	12,650	12,600	12,3
	TP321H	18Cr-10Ni-Ti[g,j]	75,000	0.85	8		10,350	10,200	10,100	9,850	9,600	9,500	9,3
Seamless A53 carbon steel	A[d]		48,000	1.00	1	12,000	11,650	10,700	9,000				
	B[d]		60,000	1.00	1	15,000	14,350	12,950	10,800				
A106 carbon steel	A[d]		48,000	1.00	1	12,000	11,650	10,700	9,000				
	B[d]		60,000	1.00	1	15,000	14,350	12,950	10,800				
	C[d]		70,000	1.00	1	17,500	16,600	14,750	12,000				

Columns 650° onward: Max allowable stress value, lb/in², for metal te[mperatures]

The stress values tabulated include a longitudinal joint efficiency factor where applicable.

The stress values in this table may be interpolated to determine values for intermediate temperatures.

Materials listed in Table 126.1 of the ANSI Standard for which allowable stresses are not tabulated may be used. Allowable stresses for such materials shall be taken from Sections I and VIII of the ASME Boiler and Pressure Vessel Code.

[a]The grouping of materials as to *P*-number classification is made on the basis of hardenability characteristics. The *P* numbers indicated in this table are identical to those adopted by the ASME Boiler and Pressure Vessel Code. Qualification of welding procedures, welders, and welding operators is required and should comply with the ASME Boiler and Pressure Vessel Code (Section IX) except as modified by Par. 127.5.

[b]The several types and grades of material tabulated should not be used at temperatures in excess of the maximum temperatures for which the allowable stress values are indicated.

[c]For stress values below 650°F which are not tabulated in Table 1, refer to Section I, Table PG-23.1 of the ASME Boiler and Pressure Vessel Code.

[d]Upon prolonged exposure to temperatures above about 775°F, the carbide phase of carbon steel may be converted to graphite.

[e]Upon prolonged exposure to temperatures above about 875°F, the carbide phase of carbon-molybdenum steel may be converted to graphite.

[f]Upon prolonged exposure to temperatures above about 975°F, the carbide phase of chrome-molybdenum steel (with chromium under 0.60) may be converted to graphite.

[g]At temperatures over 1000°F these stress values apply only when the carbon is 0.04 percent or higher.

[h]In size 8 in and larger and schedule 140 or heavier, the minimum tensile strength may be 70,000 lb/in². In these sizes and thicknesses, the indicated allowable stresses should be reduced by the ratio of 70 divided by 75.

[i]For allowable stress values below 700°F, see Table 1.

[j]The values tabulated apply to firebox quality material.

[k]Because of the relatively low yield strength of these materials, these higher stress values were established at temperatures where the short-time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. The stress values in this range exceed 62½ percent but do not exceed 90 percent of the yield strength at temperature. Use of these stresses may result in dimensional changes due to permanent strain. These stress values are not recommended for the flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

For the properties of steel applicable to high-temperature service (as well as to ordinary service) for pipes, tubes, fittings, bolting material, etc., see Sec. 6. For a discussion of creep properties, see Sec. 5.

Piping of thickness designed in accordance with Eq. (1) may be used for any combination of pressure and temperature for which *SE* values are listed in Tables 1 and 2. The following summarizes piping-industry practice.

Steam Pressures above 250 (9,224 N/m²) and not above 2,500 lb/in² (92,237 N/m²) Temperatures not above 1100°F (593°C) For pressures in excess of 100 lb/in² (3,690 N/m²), the pipe may be seamless steel (A106), (A312), (A335), or (A376); or electric-fusion-welded steel (A155); or forged-and-bored steel (A369); or automatic-welded steel (A312). For pressures between 250 and 600 lb/in² (9,224 and 22,137 N/m²) the pipe may be seamless steel (A106) or (A53); electric-fusion-welded steel (A155); electric-resistance-welded steel (A135) or (A53). For pressures of 250 lb/in² (9,224 N/m²) and lower and for service up to 750°F (399°C), any of the following may be used: electric-fusion-welded steel (A134) or (A139); electric-resistance-welded steel (A53); or Grade A electric-welded pipe (A53), (A135), or (A139) is used for close coiling or cold bending. Pipe permissible for services specified may be used for temperatures higher than 750°F (399°C), unless otherwise prohibited, if the *SE* values of Tables 1 and 2 are used when calculating the required wall thickness.

Valves and fittings must have flange openings or welded ends, and valves must have external stem threads. Valves must be of cast or forged steel or of forged or cast nonferrous material. Forged and cast-steel screwed valves and fittings may be used up to 300 lb/in² and 500°F for 3 (2) [1½] in pipe, and pressure from 250 to 400 (400 to 600) [600 to 2,500] lb/in². Malleable-iron screwed fittings (300 lb MSS SP-31) may be used for pressures not greater than 300 lb/in² and temperatures not over 500°F. Valves 8 in and larger should have the bypass of at least ¾ in, commercial size.[1] Welded fittings may be used of the same material and thickness as the pipe with which they are to be used.

Steam Pressures from 125 to 250 lb/in² (4,612 to 9,224 N/m²), Temperature not above 450°F (232°C) Pipe may be electric-fusion-welded steel (A134 or A139), electric-resistance-welded steel (A135), seamless or welded steel (A53), or wrought iron (A72). Copper and brass may be used if the temperature does not exceed 406°F. Cast iron may also be used. For close coiling or cold bending, Grade A seamless steel (A53); or Grade A electric-welded steel (A53), (A135), or (A139) is suitable. Pipe permissible for this service may be used for temperatures above 450°F (232°C) if the proper *SE* is used in calculating the pipe-wall thickness.

Valves below 3 in may have inside stem screws. Stop valves 8 in and over must be bypassed. Bodies, bonnets, and yokes are of cast iron, malleable iron, steel, bronze, brass, or Monel. Flanged-steel fittings must conform to the 300 lb ANSI Standard B16.5, if of cast iron, to the 250 lb ANSI Standard B16.2; or, for screwed fittings, to the ANSI Standard B16.4. Malleable-iron screwed fittings must conform to the 300 lb MSS SP-31 specifications, except that the 150 lb ANSI Standard B16.3 may be used for pressures not greater than 150 lb. Welded fittings may be used.

Steam Pressures from 25 to 125 lb/in², Temperatures not above 450°F Pipe may be of steel, wrought iron, cast iron, copper, or brass; valve bodies of cast iron, malleable iron, steel, or brass. Fittings are of 125 lb or 150 lb American Standard cast iron with screwed or flanged ends, or of malleable iron with screwed ends.

Steam Pressures 25 lb/in² and less, Temperature up to 450°F Pipe may be of steel, wrought iron, spiral-riveted steel, brass, copper, or cast iron. Flanged fittings conform to the 25 lb ANSI Standard B16.2. Screwed fittings are of the 125 ANSI Standard B16.4 or of the 150 lb ANSI Standard B16.3 for cast iron or malleable iron, respectively, or the B16.15 for bronze. Welded fittings may be used.

Pipe coils are made from any of the commercial sizes of iron, steel, brass, and copper pipe and tubing. Limiting center-to-center dimensions, to which pipe coils can be fabricated in sizes ¾ to 2 in, are given in Table 10. Steel tubing cannot be bent to the absolute limits of brass or copper.

Seamless mechanical tubing is obtainable in outside diameters ranging from ¼ to 10¾ in in wall thickness from 20 gage to 2 in (0.091 to 5.08 cm), and in standard pipe weights and

Table 1. Allowable Stress Values for Temperatures up to 650°F (343.4°C)
(ANSI B36.1.0—1967)

ASTM spec. No.	Grade	Nominal composition	Spec. min tensile	Longitudinal joint efficiency factor	P No.[a]	Max allowable stress value, lb/in², for metal temperatures not exceeding °F[b]: −20 to 100	200	300	400[c]	450	500	600	650
Pipe:													
Welded carbon steel, butt-welded A120,					1	6,500	6,350	6,100	5,850	5,700			
Lap-welded A120,					1	8,800	8,600	8,200	7,800	7,600			
Automatically welded austenitic steel, A312	TP304H[c,e]	18Cr-8Ni	75,000	0.85	8	15,950	14,050	13,200	12,700		12,350	12,200	12,150
	TP304H[c]	18Cr-8Ni	75,000	0.85	8	15,950	13,600	11,700	10,400		9,700	9,200	9,050
	TP316H[c,e]	18Cr-12Ni-Mo	75,000	0.85	8	15,950	14,850	14,350	13,850		13,600	13,600	13,600
	TP316H[c]	18Cr-12Ni-Mo	75,000	0.85	8	15,950	13,700	12,400	11,450		10,700	10,100	9,850
	TP321H[c,e]	18Cr-10Ni-Ti	75,000	0.85		15,950	14,300	13,450	13,100		12,850	12,850	12,850
	TP321H[c]	18Cr-10Ni-Ti	75,000	0.85	8	15,950	14,050	13,000	12,300		11,450	10,900	10,600
Electric-fusion-welded austenitic steel,													
A358 Class I[c,f,e]	TP304	18Cr-8Ni	75,000	1.00	8	18,750	16,550	15,550	14,950		14,550	14,350	14,300
Class I[c,f]	TP304	18Cr-8Ni	75,000	1.00	8	18,750	16,000	13,750	12,250		11,400	10,800	10,650
Class II[c,f,e]	TP304	18Cr-8Ni	75,000	0.90	8	16,900	14,900	14,000	13,450		13,100	12,900	12,900
Class II[c,f]	TP304	18Cr-8Ni	75,000	0.90	8	16,900	14,400	12,400	11,000		10,250	9,700	9,600
Class I[c]	TP316	18Cr-12Ni-Mo	75,000	1.00	8	18,750	17,500	16,900	16,300		16,000	16,000	16,000
Class I[c]	TP316	18Cr-12Ni-Mo	75,000	1.00	8	18,750	16,100	14,600	13,500		12,600	11,900	11,600
Class II[c,e]	TP316	18Cr-12Ni-Mo	75,000	0.90	8	16,900	15,750	15,200	14,700		14,400	14,400	14,400
Class II[c]	TP316	18Cr-12Ni-Mo	75,000	0.90	8	16,900	14,500	13,150	12,150		11,350	10,700	10,450
Class I[c,e]	TP321	18Cr-10Ni-Ti	75,000	1.00	8	18,750	16,800	15,850	15,400		15,100	15,100	15,100
Class I[c]	TP321	18Cr-10Ni-Ti	75,000	1.00	8	18,750	16,550	15,300	14,450		13,500	12,800	12,500
Class II[c,e]	TP321	18Cr-10Ni-Ti	75,000	0.90	8	16,900	15,100	14,250	13,900		13,600	13,600	13,600
Class II[c]	TP321	18Cr-10Ni-Ti	75,000	0.90	8	16,900	14,900	13,750	13,000		12,150	11,500	11,250
Seamless:													
A120 carbon steel					1	10,800	10,600	10,200	9,800	9,600			
A335 ferritic alloy[c]	P5	5Cr-½Mo	60,000	1.00	5	15,000	15,000	15,000	15,000		14,500	14,000	13,700
A335 ferritic alloy[c]	P5b	5Cr-½Mo-Si	60,000	1.00	5	15,000	15,000	15,000	15,000		14,500	14,000	13,700
A369 ferritic alloy[c]	FP5	5Cr-½Mo	60,000	1.00	5	15,000	15,000	15,000	15,000		14,500	14,000	13,700
A312 Austenitic[c,e]	TP304H	18Cr-8Ni	75,000	1.00	8	18,750	16,550	15,550	14,950		14,550	14,350	14,300
Austenitic[c]	TP304H	18Cr-8Ni	75,000	1.00	8	18,750	16,000	13,750	12,250		11,400	10,800	10,650
Austenitic[c,e]	TP316H	18Cr-12Ni-Mo	75,000	1.00	8	18,750	17,500	16,900	16,300		16,000	16,000	16,000
Austenitic[c]	TP316H	18Cr-12Ni-Mo	75,000	1.00	8	18,750	16,100	14,600	13,500		12,600	11,900	11,600
Austenitic[c,e]	TP321H	18Cr-10Ni-Ti	75,000	1.00	8	18,750	16,800	15,850	15,400		15,100	15,100	15,100
Austenitic[c]	TP321H	18Cr-10Ni-Ti	75,000	1.00	8	18,750	16,550	15,300	14,450		13,500	12,800	12,500
A376 Austenitic[c,e]	TP304H	18Cr-8Ni	75,000	1.00	8	18,750	16,550	15,550	14,950		14,550	14,350	14,300
Austenitic[c]	TP304H	18Cr-8Ni	75,000	1.00	8	18,750	16,000	13,750	12,250		11,400	10,800	10,650
Austenitic[c,e]	TP316H	18Cr-12Ni-Mo	75,000	1.00	8	18,750	17,500	16,900	16,300		16,000	16,000	16,000
Austenitic[c]	TP316H	18Cr-12Ni-Mo	75,000	1.00	8	18,750	16,100	14,600	13,500		12,600	11,900	11,600
Austenitic[c,e]	TP321H	18Cr-10Ni-Ti	75,000	1.00	8	18,750	16,800	15,850	15,400		15,100	15,100	15,100
Austenitic[c]	TP321H	18Cr-10Ni-Ti	75,000	1.00	8	18,750	16,550	15,300	14,450		13,500	12,800	12,500
A430 Austenitic[c,e]	FP304H	18Cr-8Ni	70,000	1.00	8	17,500	15,450	14,500	13,950		13,550	13,350	13,300
Austenitic[c]	FP304H	18Cr-8Ni	70,000	1.00	8	17,500	15,450	13,750	12,250		11,400	10,800	10,650
Austenitic[c,e]	FP316H	18Cr-12Ni-Mo	70,000	1.00	8	17,500	16,350	15,750	15,200		14,950	14,950	14,950
Austenitic[c]	FP316H	18Cr-12Ni-Mo	70,000	1.00	8	17,500	16,100	14,600	13,500		12,600	11,900	11,600
Austenitic[c,e]	FP321H	18Cr-10Ni-Ti	70,000	1.00	8	17,500	15,700	14,800	14,350		14,100	14,100	14,100
Austenitic[c]	FP321H	18Cr-10Ni-Ti	70,000	1.00	8	17,500	15,700	14,800	14,350		13,500	12,800	12,500

PROBABLE
COST
DEVELOPMENT

COST ESTIMATE ANALYSIS

INVITATION NO./CONTRACT NO.

EFFECTIVE PRICING DATE

DATE PREPARED 11-14-95

PROJECT Holston AAP Area B Nitric Acid

☐ CODE A ☐ CODE B ☐ CODE C

DRAWING NO.

SHT OF

LOCATION Kingsport, Tenn.

☐ OTHER

ESTIMATOR PDC

CHECKED BY

TASK DESCRIPTION	QUANTITY		LABOR				EQUIPMENT		MATERIAL		TOTAL	SHIPPING	
ECO No. 1	No. of Units	Unit Meas	MH/Unit	Total Hrs	Unit Price	Cost	Unit Price	Cost	Unit Price	Cost		Unit WT	Total WT
Steam Piping:													
6"⌀ Sch. 40 Undrgr.	250	LF			16.55	4138	1.28	320	31	7750	12208		
3"⌀ Sch. 40 Undrgr	250	LF			17.65	4413	1.28	320	19.50	4875	9608		
4"⌀ Sch 40	150	LF			11.70	1755	1.40	210	10.60	1590	3555		
2"⌀ Sch 40	150	LF			7.75	1163	.86	129	5.58	837	2129		
Pipe Insul.	300	LF				2000				1000	3000		
Turbin Mod. Cost		LS				10000				10000	20000		
15000#/HR Stm. Surf. Cnds.	1	EA				10000		2500		30000	42500		
Cond. Pump	1	EA				300				1500	1800		
8" Cndnsr. Wtr. Piping	300	LF			23	6900	1.81	543	31	9300	16743		
Pipe Ftgs & Misc.	1	LOT				10000				25000	35000		
						50669		4022		91852	146543		
TOTAL THIS SHEET													

PAGE

COST ESTIMATE ANALYSIS

PROJECT Holston AAP Area B Acid	INVITATION/P.O./CONTRACT NO.	EFFECTIVE PRICING DATE	DATE PREP. 11-14-95
LOCATION Kingsport, Tenn	☐ CODE A ☐ CODE B ☐ CODE C ☐ OTHER	DRAWING NO. ESTIMATOR PDL	SHT OF CHECKED BY

TASK DESCRIPTION	QUANTITY		LABOR				EQUIPMENT		MATERIAL		TOTAL	SHIPPING	
ECO No. 2	No. of Units	Unit Meas	MH/Unit	Total Hrs	Unit Price	Cost	Unit Price	Cost	Unit Price	Cost		Unit WT	Total WT
Steam Piping													
8" ϕ Sch. 80 Unhng.	250	LF			17.40	4350	1.28	320	33.50	8375	13045		
3" ϕ Sch. 80 Unhng.	250	LF			17.65	4413	1.28	320	19.50	4875	9608		
8" ϕ Sch. 40 on Hang.	150	LF			23	3430	1.81	272	31	4650	8372		
2" ϕ Sch. 80 on Hng.	150	LF			7.75	1163	.86	129	5.50	837	2129		
Pipe Insul.	1	LOT				2500				1200	3700		
Dowtherm Pipe:													
2½" ϕ Sch. 40	200	LF			9.20	1840	1.12	224	6.40	1280	3344		
Pipe Insul.	1	LOT				2000				1000	3000		
Hi Temp Pump (90gpm)	1	EA				300				3438	3738		
65 GPM Pump	1	EA				216				1375	1591		
N_2 Blnkt Syst	1	EA				250				1000	1250		
Unfired Blr. Vessel	1	EA				5000		2500		75000	82500		
Misc. Acces. & Fittngs	1	LOT				20000				40000	60000		
						——		——		——	——		
						45482		3165		143030	192277		
TOTAL THIS SHEET													

PAGE

COST ESTIMATE ANALYSIS

PROJECT	INVITATION NO./CONTRACT NO.	EFFECTIVE PRICING DATE	DATE PREPARED
	☐ CODE A ☐ CODE B ☐ CODE C	DRAWING NO.	SHT OF
LOCATION	☐ OTHER	ESTIMATOR	CHECKED BY

TASK DESCRIPTION	QUANTITY		LABOR				EQUIPMENT		MATERIAL		TOTAL	SHIPPING	
ECO No. 3	No. of Units	Unit Meas	MH/Unit	Total Hrs	Unit Price	Cost	Unit Price	Cost	Unit Price	Cost		Unit WT	Total WT
FBRGL, CLNG, TASK, PKG.													
600 GPM IND. DR.	1	EA				1500		1000		12000	14500		
PUMPS & PIPNG	1	LOT				3500				7200	10700		
ELECT		LS				3000				5000	8000		
SITEWORK/PATHS		LS				5000				1000	6000		
						—		—		—	—		
						13000		1000		25200	39200		
TOTAL THIS SHEET													

PAGE

COST ESTIMATE ANALYSIS

INVITATION NO./CONTRACT NO.	EFFECTIVE PRICING DATE	DATE PREPARED 11-2-95	
PROJECT HOLSTON AAP AREA B NITRIC ACID	☐ CODE A ☐ CODE B ☐ CODE C	DRAWING NO.	SHT OF
LOCATION KINGSPORT TENN	☐ OTHER	ESTIMATOR PDL	CHECKED BY

TASK DESCRIPTION	QUANTITY		LABOR				EQUIPMENT		MATERIAL		TOTAL	SHIPPING	
	No. of Units	Unit Meas	MH/Unit	Total Hrs	Unit Price	Cost	Unit Price	Cost	Unit Price	Cost		Unit WT	Total WT
INSULATION ECO #4													
1" CALCIUM SILICATE:													
18"Φ AIR PRHTR.	12	LF			5.40	64.80			9.35	112.20	177.–		
18"Φ TAILGAS HTR.	25	LF			5.40	135.–			9.35	233.75	368.75		
8"Φ TLGS. PIPE TO TURB.	120	LF			3.84	460.80			4.26	511.20	972.–		
0.010 S.S. JACKET:													
18"Φ AIR PRHTR	60	SF			4.03	241.80			.93	55.80	297.60		
18"Φ TAILGAS HTR	125	SF			4.03	503.75			.93	116.25	620.–		
8"Φ TLGS. PIPE TO TURB	315	SF			4.03	1269.45			.93	292.95	1562.40		
18"Φ FLANGE SETS (INSUL)	10	SF			13.45	134.50			2.71	27.10	161.60		
18"Φ FL. SETS (JACKET)	10	SF			4.03	40.30			.93	9.30	49.60		
SUBTOTAL						2850.40				1358.55	4208.95		
15% CONTING.											631.35		
TOTAL CONST. – USE											4850.–		
TOTAL THIS SHEET													

COST ESTIMATE ANALYSIS

COST ESTIMATE ANALYSIS	INVITATION NO./CONTRACT NO.	EFFECTIVE PRICING DATE	DATE PREPARED
PROJECT	☐ CODE A ☐ CODE B ☐ CODE C	DRAWING NO.	SHT OF
LOCATION	☐ OTHER	ESTIMATOR	CHECKED BY

TASK DESCRIPTION	QUANTITY		LABOR				EQUIPMENT		MATERIAL		TOTAL	SHIPPING	
ECO No. 5	No. of Units	Unit Meas	MH/Unit	Total Hrs	Unit Price	Cost	Unit Price	Cost	Unit Price	Cost		Unit WT	Total WT
18" SEMICIRCULAR													
PLATE HT. EXCH. 14' LNG.	1	EA				100				5000	5100		
CLAYTON WHSG WASTE													
HEAT STEAM GENERATOR	1	EA				2000				5000	7000		
CONDENSATE COOLER	1	EA				100				500	600		
COND. RCVR/PUMP	1	EA				300				1500	1800		
1¼" Ø INSULATED													
PIPE & FITTINGS	1	LOT				7500				5000	12500		
						10000				17000	27000		
TOTAL THIS SHEET													

COST ESTIMATE ANALYSIS

PROJECT Holston Nitric Acid Prod. - ECO #7	INVITATION/CONTRACT NO.	EFFECTIVE PRICING DATE	DATE PREPARED 12-12-95
	☐ CODE A ☐ CODE B ☐ CODE C	DRAWING NO.	SHT OF
LOCATION Kingsport, Tenn.	☐ OTHER	ESTIMATOR PDL	CHECKED BY

TASK DESCRIPTION	QUANTITY		LABOR				EQUIPMENT		MATERIAL		TOTAL	SHIPPING	
ECO No. 7	No. of Units	Unit Meas	MH/Unit	Total Hrs	Unit Price	Cost	Unit Price	Cost	Unit Price	Cost		Unit WT	Total WT
Makeup & Fdwtr. Pipe - 1"Φ	500	LF			4^{65}	2325	$.57$	285	2^{89}	1445	4055		
Steam Pipe - 1½"Φ	150	LF			5^{70}	855	$.69$	104	3^{96}	594	1553		
400 Series St. Stl. Econom.	1	EA				2000		500		185500	188000		
Waste Ht. Blr. Syst	1	EA				1500		150		68600	70250		
Fdwtr Pump - 4GPM/225TDH	1	EA			72^{50}	73			500	500	573		
Temperature Controls	1	SET			150	150			850	850	1000		
6"Φ A312GR.TP321 Pipe	40	LF			20	800	1^{50}	60	60	2400	3260		
Heater Insulation		LS				2850				1360	4210		
Steam Pipe Insul	150	LF			2^{49}	374			2^{23}	335	709		
Fdwtr Pipe Insul	150	LF			2^{42}	363			2^{16}	324	687		
Surge Tank - 100 Gal	1	EA				25				100	125		
Pipe Fittings & Acces.	1	LOT				2000		—		5500	7500		
						13315		1099		267508	281922		
15% Contingency													
					Cost W.O. St. Stl. Sect.						93922		
TOTAL THIS SHEET													

PAGE

AEI
AFFILIATED ENGINEERS SE, INC.
3300 SW Archer Road
Gainesville, Florida 32608
(904) 376-5500
FAX (904) 375-3479

Made By: PDL	Date: 12-22-95	Job No: 95094-00
Checked By:	Date:	Sheet No: ___ of ___

Calculations For: ECO #7 COSTS

ASSUMPTIONS

(1) COST OF ST. STL. FABRICATION IS PROPORTIONAL TO PUBLISHED COST MULTIPLIER FOR 90° PIPE ELBOW FROM MEANS:

SCH. 40 12"Φ 316SS 90° ELBOW - $1720 MATERIAL

SCH 40 12"Φ BL. IRON 90° ELBOW - $212 MATERIAL

$$\text{MULTIPLIER} = \frac{1720}{212} = 8.1$$

(2) PUMP AND ACCUMULATOR SKIDS AND BACK PRESSURE REGULATOR INCLUDED IN CLAYTON QUOTATION WILL SERVE BOTH GENERATORS

(3) STANDARD GENERATOR COST IS 1/3 OF TOTAL QUOTED COST.

ADDED COST FOR ST. STL. GENERATOR WHICH CLAYTON DECLINED TO QUOTE:

$$\text{COST} = \frac{\$68600}{3}(8.1) = \$185522$$

P10069

Clayton INDUSTRIES

P.O. BOX 5530, EL MONTE, CALIFORNIA 91734-1530 TEL (818) 443-9381 FAX (818) 442-1701

QUOTATION No. G-11623

TO: Affiliated Engineers SE, Inc.
3300 SW Archer Road
Gainesville, Florida 32608-1731

TERMS: 20% with Order-Balance Net 30
Subject to Credit Approval

ATTN: Paul Little
(904) 376-5500 -TEL
(904) 375-3479 -FAX

FOB: El Monte, CA - Prepay and Add
APPROX. SHIP DATE: 120 Days
AFTER RECEIPT AND ACCEPTANCE OF ORDER

RE: Clayton Steam Generator

QUANT.	MODEL AND SPECIFICATIONS	UNIT PRICE	TOTAL
1	<u>EGSG-5EC0201 Exhaust Gas Steam Generator</u> Mono-coil, smooth tube, single pass Steam Generator Designed to maintian feedwater inlet temperatrue to prevent dewpoint corrosion while maintaining High efficiency. <u>Conditions</u> Gas Flow: 20,000 lb/h T gas in: 495 °F T gas out: 266 °F Gas Press Drop: 17.4 inW.C. Steam Flow: 1,180 pph Steam Press: 80 psig		
1	<u>Bottom Inlet/Top Outlet Cones</u> Provide transition pieces from 32 inch O.D. exhaust stack to the EGSG. Includes Soot Blower Ring on Inlet Side.		
1	<u>Pump & Accumulator Skids</u> Includes the following items mounted on a skid: 1 Feed Pump & Electric Motor Accumulator with Level Control & Pressure Gauge Control Box Including Starter for Clayton Pump Safety Valve(s) Overflow Steam Trap Necessary piping and wiring with-in skid boundary		
1	Back Pressure Regulator. For stabilizing steam system during load fluctuation and operation start-up.		
	TOTAL: HEAT RECOVERY SYSTEM		**$68,610**
	NOTE: Freight, Sales Tax, and other fees may apply.		

THIS QUOTATION EXPIRES in 30 Days, AND IS SUBJECT TO THE TERMS AND CONDITIONS ON THE FACE AND THE REVERSE SIDE HEREOF. PARAGRAPH 17 OF SUCH TERMS AND CONDITIONS LIMITS ACCEPTANCE OF THIS QUOTATION TO THE TERMS CONTAINED HEREIN, EXCLUDES ANY ADDITIONAL TERMS PROPOSED BY PURCHASER, AND PROVIDES THAT ANY ORDER BY PURCHASER BASED ON THIS QUOTATION (OR ACCEPTANCE BY PURCHASER OF THE GOODS DESCRIBED HEREIN) SHALL CONSTITUTE AN UNCONDITIONAL ACCEPTANCE BY PURCHASER OF EACH AND ALL OF THE TERMS AND CONDITIONS CONTAINED HEREIN, AND A WAIVER BY PURCHASER OF ANY CONFLICTING OR ADDITIONAL PROVISIONS CONTAINED IN ANY OF PURCHASERS DOCUMENTS RELATING TO THIS TRANSACTION.

ACCEPTANCE

THIS QUOTATION IS ACCEPTED

COMPANY ______________________

BY ______________________
NAME TITLE DATE

SUBMITTED BY

Nick LeJeune

Nick LeJeune - Sales Engineer - 12/22/95 a.m.

SIGNATURE TITLE DATE

STEAM GENERATORS EXHAUST GAS & WASTE HEAT BOILERS

Affiliated Engineers SE, Inc.
3300 SW Archer Road
Gainesville, FL 32608

Telephone Conversation

Conversation With: ~~NICK LOJUENE~~

Representing: CLAYTON

Project Name: HOLSTON AAP NITRIC ACID FAC.

Location: KINGSPORT, TENN.

Routing:

Project Number: 95094-00

Date: 12-22-95

Time:

FAXED ONE PAGE QUOTE.

CLAYTON DECLINED TO QUOTE THE STAINLESS STEEL SECTION BECAUSE OF THE NITRIC ACID FORMED.

By: Paul D. Liddell

AEI
Affiliated Engineers SE, Inc.
3300 SW Archer Road
Gainesville, Florida 32608-1731

(904)376-5500 - Office
(904)375-3479 - Fax

FAXED

FAX TRANSMISSION COVER SHEET

TO:	NICK LOJUENO 770-907-2200	FAX #:	770 907-0548
COMPANY:	CLAYTON INDUSTRIES	PROJECT #:	95094-00
FROM:	PAUL LITTLE	PAGES:	3 (Incl cover sheet)
DATE-TIME:	12-11-95	Hard Copy to Follow:	NO

REMARKS:

DESIRE BUDGET PRICING & NOMINAL PERFORMANCE THAT MIGHT BE EXPECTED. I ANTICIPATE EACH UNIT WILL PRODUCE IN EXCESS OF 1000 #/HR SATURATED STEAM.

CLAYTON INDUSTRIES
HEAT RECOVERY SYSTEM
FACT SHEET FOR QUOTATION

(Designed for initial proposal only to establish size and budget estimate for basic equipment)

DATE 12-11-95

COMPANY: AESE
ADDRESS: GAINESVILLE, FL.
NAME OF CONTACT: PAUL LITTLE
PRODUCT GAS UNIT

Circle appropriate units of measure

Gas Flow Mass Units 17650	17650	(lbs/hr or Kg/hr)
Standard Volume Units (at 75°F or 24°C)		(SCFM or SM³/hr)
Gas Inlet Temperature	350	(F or C)
Steam Pressure	80	(Psi or bar)
Receiver (Feedwater) Temp. (usually 200°F or 93°C)	150	(F or C)
OPTION* 1. Gas Outlet Temperature		(F or C)
2. Total Heat Transfer		(Btu/hr or Kcal/hr)
3. Steam Mass Flow Rate		(lbs/hr or k/hr)
*(Indicate "maximum available" if unknown)		
Allowable Gas Pressure Drop	27	(In W.C. or mm - N.C.)

DEWPOINT = 255°F $C_p = 0.253$ B/#°F

Waste Gas Properties: PERCENT BY VOLUME: N_2 - 71.3; NO_2 - 11.5%; H_2O - 16.4%

Source of Waste Gas (incinerator, oven, turbine, engine, etc.): CHEMICAL PROCESS

Source of Fuel (gas, diesel oil, commercial waste, etc.): NA

Specific Gravity[1] ________ Temp. ________ Specific Heat[2] ________ Temp. ________

Indicate utilization factor, (8 hours/day, 5 days/week; or 24 hrs/day, Continuous; standby only, etc.): 24 HRS/DAY

Equipment estimate at job site (size and number of sections): ________

Equipment selection Clayton Engineering: ________

[1]Will use the following figures if not available: 1.0 @ 70°F.
[2]Will use the following figures if not available: .25 @ 600°F.

REQUIRES 400 SERIES STAINLESS STEEL GAS SIDE CONSTRUCTION. CONDENSATION IS DESIREABLE - NITRIC ACID WILL BE THE RESULT.

C-3883YOM11-88MG

DEC-11-'95 MON 17:18 ID: TEL NO: #710 P02

CLAYTON INDUSTRIES
HEAT RECOVERY SYSTEM
FACT SHEET FOR QUOTATION

(Designed for initial proposal only to establish size and budget estimate for basic equipment)

DATE 12-11-95

COMPANY: AESB

ADDRESS: GAINESVILLE, FL.

NAME OF CONTACT: PAUL LITTLE

TURBINE EXHAUST UNIT

Circle appropriate units of measure

Gas Flow	Mass Units 20000 #/HR	20000	(lbs/hr or Kg/hr)
	Standard Volume Units (at 75°F or 24°C)		(SCFM or SM³/hr)
Gas Inlet Temperature	495°F	495	(F or C)
Steam Pressure	80 PSIG	80	(Psi or bar)
Receiver (Feedwater) Temp. (usually 200°F or 93°C)		150	(F or C)
OPTION*	1. Gas Outlet Temperature		(F or C)
	2. Total Heat Transfer		(Btu/hr or Kcal/hr)
	3. Steam Mass Flow Rate		(lbs/hr or k/hr)

*(Indicate "maximum available" if unknown)

...wable Gas Pressure Drop	27	(In W.C. or mm - N.C.)

Waste Gas Properties: PERCENT BY VOLUME: N_2-80.2; NO-4.9%; H_2O-13.9%

Source of Waste Gas (incinerator, oven, turbine, engine, etc.): CP = 0.263 B/#°F

Source of Fuel (gas, diesel oil, commercial waste, etc.): N.A.

Specific Gravity[1] ________ Temp. ________ Specific Heat[2] ________ Temp. ________

Indicate utilization factor, (8 hours/day, 5 days/week; or 24 hrs/day, Continuous; standby only, etc.): 24 HR/DAY

Equipment estimate at job site (size and number of sections): ________

Equipment selection Clayton Engineering: ________

[1]Will use the following figures if not available: 1.0 @ 70°F.
[2]Will use the following figures if not available: .25 @ 600°F.

C-3800/1OM/11-89/MG

ENERGY RATE SOURCE MATERIAL

J. Bouchillon, PE
3/95
Rec'd from J. Bouchillon 7/6/95 RB

1994 OUT-OF-POCKET COST FOR STEAM, B-200

GIVEN: 1994 AREA B MONTHLY USAGE & PROD. REPORT, by KEN HARRIS

Sum of individual boiler's steam output = 1,324,620,000 lbs

Building Steam Output = Sum − internal consumption (turbines, DA, etc)

16.4% (EEAP study, EMC Engineers 1992, p. C-4)

= 1,324,620,000 × .836 = 1,107,382.000 lbs

= 1,107 m Btu

Steam Coal, 1994 = 64,673 tons

(Per HDC coal purch spec June 1994)

Btu content of coal = 64,673 tons × 2000 × 14,100 $\frac{BTU}{lb}$

= 1,824 m m Btu

Cost of treatment of Sulfuric System backwash water = − Utilities Cost Report

50 gpm ave × 60 $\frac{min}{hr}$ × 8760 × \$.239/1000 gal = \$6,500/yr.

COST of Filter Water for feed water = − Utilities Cost Report

$\frac{1,324,620,000 \text{ lbs}}{8 \text{ lbs water/gal}} \times \frac{\$0.148}{1000 \text{gal}}$ = \$24,500/yr

Cost of electricity (motors, precipitators, etc) =

Cost ctr 2235 — per mar '95 elec bill

412,000 $\frac{KWH}{mo}$ (ave) × .035 $\frac{\$}{KWH}$ × 12 mo = \$173,000/yr

Cost of fly ash disposal = 15,000 est

cost of cinder removal = 10,000 est

[cost of bldg maintenance = \$393,391 routine + \$529,104 major = \$922,465]

COST of water treatment Chemicals (See Osmosis Study JLB 1995) \$91,000

Out of Pocket Steam Cost = $\frac{\text{Coal + electricity + water softening chemicals + FW + waste water treatmt + flyash + cinder disposal}}{\text{bldg steam output}}$

per Defense fuels, Geo. Tittsworth 3/95 — \$2.91 million

OPSC = $\frac{(\$45 \times 64,673) + \$173,000 + \$91,000 + \$24,500 + \$6520 + 15,000 + 10,000}{1,107,382,000 \text{ lbs}}$

= $\frac{3.23 \text{ million}}{1,107}$ = $\boxed{2.92 \frac{\$}{1000 \text{ lbs}}}$

3.75 $\frac{\$}{K lbs}$ Counting maintenance

Kingsport Power Company
PO BOX 11? KINGSPORT TN 3766?

1-615-578-2200

Account Number
R | 1 | 111 | 93 | 13000 | 0 | 4 |

HOLSTON ARMY AMM PLANT
PO-052-0701 CONT# DAAA09-70-C-0320
P O BX 749
KINGSPORT TN 37662

1011931300034 0140028750140028757

MARCH 1995

Please Return This Portion With Your Payment

Gross Amount	Last Pay Date For Net Amount	Net Amount
14?,?23.75	APR 12	140,028.75

Meter Types
K - Kilowatt Hour
D - KW Demand
A - KVA Demand
R - RKVAH
V - KVAR Demand

Codes
E - Estimated
C - Meter Change
O - Off Peak

Account Number: (Please Use When You Call or Write)
1 111 93 13000 0 4

Service Address
HOLSTON ARMY AMM PLANT
CONTR NO R-1921-ENG-5
KINGSPORT TN 37660

Month MARCH 1995 Tariff 324 IP TRAN Office KINGSPORT

Service From	Service To	Type	Meter Number	Previous Readings	Present Readings	Meter Constant	Metered Usage	Voltage Constant
02-23	03-24	K	34741	07389	57558	24000.	4056000	
02-23	03-24	R	34740	34572	34627	24000.	1320000	
02-23	03-24	D	34741		.331	24000.	7944.0	
02-23	03-24	V	34740		.154	24000.	3696.0	
02-23	03-24	K	33223	0038	0038	6000.		
02-23	03-24	D	33223		[illegible]	6000.	120.0	
02-23	03-24	R	33223	0330	0340	6000.	60000	
02-23	03-24	V	33223		.025	6000.	150.0	

Contract Capacity	10,500
Billing KVAH	
RKVAH	1,380,000
Metered Demand	8,064.0
Power Factor	
Billing Demand	8,064.0
Metered KWH	4,056,000
Power Factor Constant	
Adjusted KWH	4,056,000
Voltage Adj KWH	
Billing KWH	4,056,000

RATE BILLING		154,111.36
FUEL ADJ	.0029462-	11,950.19CR
PROMPT PAYMENT DISCOUNT		2,132.42CR
TOTAL AMOUNT DUE		140,028.75

KINGSPORT POWER

TARIFF I. P.
(Industrial Power)

AVAILABILITY OF SERVICE

Available to industrial and large commercial customers. Customers shall contract for a definite amount of electrical capacity in KW which shall be sufficient to meet normal maximum requirements but in no case shall the capacity contracted for be less than 3,000 KW. Contract capacities will be specified in multiples of 100 KW.

MONTHLY RATE

Tariff Code	Service Voltage	Demand Charge per KW	Energy Charge per KWH	Service Charge	
322	Primary	$ 8.70	2.302 cents	$ 240.00	
323	Subtransmission	$ 7.79	2.269 cents	$ 730.00	
324	Transmission	$ 7.60 HDC	2.241 cents	$1,930.00	HDC

Reactive Demand Charge for each Kilovar of Lagging Reactive Demand in excess of 50 percent of the KW of monthly metered demand . . . . $ 0.75 per KVAR

MINIMUM CHARGE

This tariff is subject to a minimum monthly charge equal to the sum of the service charge, the product of the demand charge and the monthly billing demand and the fuel clause adjustment.

FUEL CLAUSE

When the unit cost of fuel in the charges for power purchased from Appalachian Power Company under Federal [illegible]rgy Regulatory Commission rate schedule No. 23 is above or below a base unit price of 15.8563 mills per KWH, adjusted for losses, the bill for service shall be increased or decreased respectively at a rate per KWH equal to the amount that such cost of fuel is above or below the unit base cost of 15.8563 mills per KWH, adjusted for losses, applied to the KWH measured in the period for which the bill is rendered. The adjustment shall be based on the most recent calendar month for which fuel cost data is available.

PROMPT PAYMENT DISCOUNT

A discount of 1.5 percent will be allowed if account is paid in full within 15 days of date of bill.

DETERMINATION OF DEMAND

The billing demand in KW shall be taken each month as the single highest 30-minute integrated peak in KW as registered during the month by a demand meter or indicator, or, at the Company's option, as the highest registration of a thermal type demand meter or indicator, but the monthly billing demand so established shall in no event be less than 60% of the greater of (a) the customer's contract capacity or (b) the customer's highest previously established monthly billing demand during the past 11 months nor less than 3,000 KW.

The reactive demand in KVARS shall be taken each month as the single highest 30-minute integrated peak in KVARS as registered during the month by a demand meter or indicator, or, at the Company's option, as the highest registration of a thermal type demand meter or indicator.

METERED VOLTAGE

The rates set forth in this tariff are based upon the delivery and measurement of energy at the same voltage, thus measurement will be made at or compensated to the delivery voltage. At the sole discretion of the Company, such compensation may be achieved through the use of loss compensating equipment, the use of formulas to calculate losses or the application of multipliers to the metered quantities. In such cases, the metered KWH and KW values will be adjusted for billing purposes. If the Company elects to adjust KWH and KW based on multipliers, the adjustments shall be in accordance with the following:

1. Measurements taken at the low-side of a customer-owned transformer will be multiplied by 1.01.
2. Measurements taken at the high-side of a Company-owned transformer will be multiplied by 0.98.

SCOPE
OF
WORK

DEPARTMENT OF THE ARMY
MOBILE DISTRICT, CORPS OF ENGINEERS
P. O. BOX 2288
MOBILE, ALABAMA 36628-0001

RECEIVED
Affiliated Engineers SE, Inc.
APR 10 1995
Route to CO 4/10/95
CC: 10/5

April 4, 1995

REPLY TO
ATTENTION OF:

A-E Contracts
Section

Affiliated Engineers SE, Inc.
Mr Carl L. Osberg
3300 SW Archer Road
Gainesville, FL 32608-1731

Gentlemen:

We have a requirement for a Limited Energy Study for Area B Nitric Acid Production Facilities at Holston AAP, TN, in accordance with the enclosed Scope of Work and as will be further defined at the pre-study conference on April 26 at Holston. It is proposed that this work be accomplished by delivery order under Contract Number DACA01-94-D-0007.

You are requested to submit your proposal for accomplishing this work by May 10, 1995. Your proposal should be addressed as follows:

District Engineer
U. S. Army Engineer District, Mobile
Attention: CESAM-EN-MN/Mr. Dan Mizelle
Post Office Box 2288
Mobile, Alabama 36628-0001

You are cautioned that no services for which an additional cost or fee will be charged should be furnished without the prior written authorization of the Contracting Officer.

Please contact Mr. Roger D. Baer at 205/441-5493 if you have any questions concerning this matter.

Sincerely,

O. B. Anderson

O. B. Anderson
Authorized Representative
of the Contracting Officer

CESAM-EN-DM

1 February 1995
Revised 21 March 1995

SCOPE OF WORK

FOR A

LIMITED ENERGY STUDY

AREA B NITRIC ACID PRODUCTION FACILITIES

HOLSTON ARMY AMMUNITION PLANT, TENNESSEE

Performed as part of the

ENERGY ENGINEERING ANALYSIS PROGRAM (EEAP)

HAOPSOW.doc

SCOPE OF WORK
FOR A
LIMITED ENERGY STUDY

AREA B NITRIC ACID PRODUCTION FACILITIES
HOLSTON ARMY AMMUNITION PLANT, TENNESSEE

TABLE OF CONTENTS

ANNEXES

1. <u>BRIEF</u> <u>DESCRIPTION</u> <u>OF</u> <u>WORK</u>: The Architect-Engineer (AE) shall:

1.1 Perform a limited site survey of specific buildings or areas to collect all data required to evaluate the specific ECOs included in this study.

1.2 Evaluate specific ECOs to determine their energy savings potential and economic feasibility.

1.3 Provide project documentation for recommended ECOs as detailed herein.

1.4 Prepare a comprehensive report to document all work performed, the results and all recommendations.

2. <u>GENERAL</u>

2.1 This study is limited to the evaluation of the specific buildings, systems, or ECOs listed in Annex A, DETAILED SCOPE OF WORK.

2.2 The information and analysis outlined herein are considered to be minimum requirements for adequate performance of this study.

2.3 For the buildings, systems or ECOs listed in Annex A, all methods of energy conservation which are reasonable and practical shall be considered, including improvements of operational methods and procedures as well as the physical facilities. All energy conservation opportunities which produce energy or dollar savings shall be documented in this report. Any energy conservation opportunity considered infeasible shall also be documented in the report with reasons for elimination.

2.4 The study shall consider the use of all energy sources applicable to each building, system, or ECO.

2.5 The "Energy Conservation Investment Program (ECIP) Guidance", described in letter from DAIM-FDF-U, dated 10 Jan 1994 establishes criteria for ECIP projects and shall be used for performing the economic analyses of <u>all</u> ECOs and projects. The program, Life Cycle Cost In Design (LCCID), has been developed for performing life cycle cost calculations in accordance with ECIP guidelines and is referenced in the ECIP Guidance. If any program other than LCCID is proposed for life cycle cost analysis, it must use the mode of calculation specified in the ECIP Guidance. The output must be in the format of the ECIP LCCA summary sheet, and it must be submitted for approval to the Contracting Officer.

2.6 The following definitions apply to terms used in this scope of work:

2.6.1 "Contracting Officer", "Contracting Officer's Representative", or Government's Representative" refer to the contracting office of the Mobile District, U. S. Army Corps of Engineers.

2.6.2 "Installation Commander", or "Installation Representative" refer to the military commander of Holston Army Ammunition Plant.

2.6.3 "Plant Manager", Operating Contractor", or "Operating Contractor's Representative" refer to the Holston Defense Corporation, which operates Holston Army Ammunition Plant under contract to the U. S. Army.

2.7 Energy conservation opportunities determined to be technically and economically feasible shall be developed into projects acceptable to installation personnel. This may involve combining similar ECOs into larger packages which will qualify for ECIP or O&M funding, and determining in coordination with installation personnel the appropriate packaging and implementation approach for all feasible ECOs.

2.7.1 Projects which qualify for ECIP funding shall be identified, separately listed, and prioritized by the Savings to Investment Ratio (SIR).

2.7.2 All feasible non-ECIP projects shall be ranked in order of highest to lowest SIR.

2.8 Metric Reporting Requirements: In this study, the analyses of the ECOs may be performed using English or Metric units as long as they are consistent throughout the report. The final results of energy savings for individual recommended projects and for the overall study will be reported in units of MegaBTU per year <u>and</u> in MegaWattHours per year. Paragraph 7.4.2 details requirements for the contents of the final submittal.

3. <u>PROJECT MANAGEMENT</u>

3.1 <u>Project Managers</u>. The AE shall designate a project manager to serve as a point of contact and liaison for work required under this contract. Upon award of this contract, the individual shall be immediately designated in writing. The AE's designated project manager shall be approved by the Contracting Officer prior to commencement of work. This designated individual shall be responsible for coordination of work required under this contract. The Contracting Officer will designate a project manager to serve as the Government's point of contact and liaison for all work required under this contract. This individual will be the Government's representative.

3.2 <u>Installation Assistance</u>.

3.2.1. The Installation Commander will designate an individual to coordinate between the AE and the Holston Defense Corporation. This individual will be the Installation Representative, and all correspondence with Holston Army Ammunition Plant will be addressed to his attention.

3.2.2. The Plant Manager will designate an individual to assist the AE in obtaining information and establishing contacts necessary to accomplish the work required under this contract. This individual will be the Operating Contractor's Representative.

3.3 Public Disclosures. The AE shall make no public announcements or disclosures relative to information contained or developed in this contract, except as authorized by the Contracting Officer.

3.4 Meetings. Meetings will be scheduled whenever requested by the AE or the Contracting Officer for the resolution of questions or problems encountered in the performance of the work. The AE's project manager and the Government's representative shall be required to attend and participate in all meetings pertinent to the work required under this contract as directed by the Contracting Officer. These meetings, if necessary, are in addition to the presentation and review conferences.

3.5 Site Visits, Inspections, and Investigations. The AE shall visit and inspect/investigate the site of the project as necessary and required during the preparation and accomplishment of the work.

3.6 Records

3.6.1 The AE shall provide a record of all significant conferences, meetings, discussions, verbal directions, telephone conversations, etc., with Government representative(s) relative to this contract in which the AE and/or designated representative(s) thereof participated. These records shall be dated and shall identify the contract number, delivery order number, participating personnel, subject discussed and conclusions reached. The AE shall forward to the Contracting Officer within ten calendar days, a reproducible copy of the records.

3.6.2 The AE shall provide a record of requests for and/or receipt of Government-furnished material, data, documents, information, etc., which if not furnished in a timely manner, would significantly impair the normal progression of the work under this contract. The records shall be dated and shall identify the contract number and modification number, if applicable. The AE shall forward to the Contracting Officer within ten calendar days, a reproducible copy of the record of request or receipt of material.

3.7 Interviews. The AE and the Government's representative shall conduct entry and exit interviews with the Plant Manager before starting work at the installation and after completion of the field work. The Government's representative shall schedule the interviews at least one week in advance.

3.7.1 Entry. The entry interview shall describe the intended procedures for the survey and shall be conducted prior to commencing work at the facility. As a minimum, the interview shall cover the following points:

a. Schedules.

b. Names of energy analysts who will be conducting the site survey.

c. Proposed working hours.

d. Support requirements from Holston Defense Corporation (HDC).

3.7.2 Exit. The exit interview shall briefly describe the items surveyed and probable areas of energy conservation. The interview shall also solicit input and advice from the Plant Manager.

4. SERVICES AND MATERIALS. All services, materials (except those specifically enumerated to be furnished by the Government), labor, supervision and travel necessary to perform the work and render the data required under this contract are included in the lump sum price of the contract.

5. PROJECT DOCUMENTATION. All energy conservation opportunities which the AE has considered shall be included in one of the following categories and presented in the report as such:

5.1 ECIP Projects. To qualify as an ECIP project, an ECO, or several ECOs which have been combined, must have a construction cost estimate greater than $300,000, a Savings to Investment Ratio (SIR) greater than 1.25 and a simple payback period of less than ten years. The overall project and each discrete part of the project shall have an SIR greater than 1.25. All projects meeting the above criteria shall be arranged as specified in paragraph 2.7.1 and shall be provided with programming documentation. Programming documentation shall consist of a DD Form 1391 and life cycle cost analysis (LCCA) summary sheet(s) (with necessary backup data to verify the numbers presented). A life cycle cost analysis summary sheet shall be developed for each ECO and for the overall project when more than one ECO are combined. The energy savings for projects consisting of multiple ECOs must take into account the synergistic effects of the individual ECOs.

5.2 Non-ECIP Projects. Projects which do not meet ECIP criteria with regard to cost estimate or payback period, but which have an SIR greater than 1.25 shall be documented. Projects or ECOs in this category shall be arranged as specified in paragraph 2.7.2 and shall be provided with the following documentation: the life cycle cost analysis (LCCA) summary sheet completely filled out, a description of the work to be accomplished, backup data for the LCCA, ie, energy savings calculations and cost estimate(s), and the simple payback period. The energy savings for projects consisting of multiple ECOs must take into account the synergistic effects of the individual ECOs. In addition these projects shall have the necessary documentation prepared, as required by the Government's representative, for one of the following categories:

5.2.1. Federal Energy Management Program (FEMP) Projects. A FEMP (or O&M Energy) project is one that results in needed maintenance or repair to an existing facility, or replaces a failed or failing existing facility, and also results in energy savings. The criteria are similar to the criteria for ECIP projects, ie, SIR $\geq$ 1.25, and simple payback period of less than ten years. Projects with a construction cost estimate up to $1,000,000 shall be documented as outlined in par 5.2 above; projects over $1,000,000 shall be documented on 1391s. In the FEMP program, a system may be defined as "failed or failing" if it is inefficient or technically obsolete. However, if this strategy is used to justify a proposed project, the equipment to be replaced must have been in use for at least three years.

5.2.2. Low Cost/No Cost Projects. These are projects which the Plant Manager can perform using his resources. Documentation shall be as required by the Plant Manager.

5.3 Nonfeasible ECOs. All ECOs which the AE has considered but which are not feasible, shall be documented in the report with reasons and justifications showing why they were rejected.

6. DETAILED SCOPE OF WORK. The Detailed Scope of Work may be found in Annex A.

7. WORK TO BE ACCOMPLISHED.

7.1 Perform a Limited Site Survey. The AE shall obtain all necessary data to evaluate the ECOs or projects by conducting a site survey. The AE shall document his site survey on forms developed for the survey, or standard forms, and submit these completed forms as part of the report. All test and/or measurement equipment shall be properly calibrated prior to its use.

7.2 Evaluate Selected ECOs. The AE shall analyze the ECOs listed in Annex A. These ECOs shall be analyzed in detail to determine their feasibility. Savings to Investment Ratios (SIRs) shall be determined using current ECIP guidance. The AE shall provide all data and calculations needed to support the recommended ECO. All assumptions and engineering equations shall be clearly stated. Calculations shall be prepared showing how all numbers in the ECO were figured. Calculations shall be an orderly step-by-step progression from the first assumption to the final number. Descriptions of the products, manufacturers catalog cuts, pertinent drawings and sketches shall also be included. A life cycle cost analysis summary sheet shall be prepared for each ECO and included as part of the supporting data.

7.3 Combine ECOs Into Recommended Projects. During the Interim Review Conference, as outlined in paragraph 7.4.1, the AE will be advised of the Plant Manager's preferred packaging of recommended ECOs into projects for implementation. Some projects may be a combination of several ECOs, and others may contain only one. These projects will be evaluated and arranged as outlined in

paragraphs 5.1, 5.2, and 5.3. Energy savings calculations shall take into account the synergistic effects of multiple ECOs within a project and the effects of one project upon another. The results of this effort will be reported in the Final Submittal per par 7.4.2.

7.4 Submittals, Presentations and Reviews. The work accomplished shall be fully documented by a comprehensive report. The report shall have a table of contents and shall be indexed. Tabs and dividers shall clearly and distinctly divide sections, subsections, and appendices. All pages shall be numbered. Names of the persons primarily responsible for the project shall be included. The AE shall give a formal presentation of the interim submittal to installation, command, and other Government personnel. Slides or view graphs showing the results of the study to date shall be used during the presentation. During the presentation, the personnel in attendance shall be given ample opportunity to ask questions and discuss any changes deemed necessary to the study. A review conference will be conducted the same day, following the presentation. Each comment presented at the review conference will be discussed and resolved or action items assigned. It is anticipated that the presentation and review conference will require approximately one working day. The presentation and review conference will be at the installation on the date agreeable to the Plant Manager, the AE and the Government's representative. The Contracting Officer may require a resubmittal of any document(s), if such document(s) are not approved because they are determined by the Contracting Officer to be inadequate for the intended purpose.

7.4.1 Interim Submittal. An interim report shall be submitted for review after the field survey has been completed and an analysis has been performed on all of the ECOs. The report shall indicate the work which has been accomplished to date, illustrate the methods and justifications of the approaches taken and contain a plan of the work remaining to complete the study. Calculations showing energy and dollar savings, SIR, and simple payback period of all the ECOs shall be included. The results of the ECO analyses shall be summarized by lists as follows:

a. All ECOs eliminated from consideration shall be grouped into one listing with reasons for their elimination as discussed in par 5.3.

b. All ECOs which were analyzed shall be grouped into two listings, recommended and non-recommended, each arranged in order of descending SIR. These lists may be subdivided by building or area as appropriate for the study. The AE shall submit the Scope of Work and any modifications to the Scope of Work as an appendix to the report. A narrative summary describing the work and results to date shall be a part of this submittal. At the Interim Submittal and Review Conference, the Government's and AE's representatives shall coordinate with the Plant Manager to provide the AE with direction for packaging or combining ECOs for programming purposes and also indicate the fiscal year for which the

programming or implementation documentation shall be prepared. The survey forms completed during this audit shall be submitted with this report. The survey forms only may be submitted in final form with this submittal. They should be clearly marked at the time of submission that they are to be retained. They shall be bound in a standard three-ring binder which will allow repeated disassembly and reassembly of the material contained within.

7.4.2 Final Submittal. The AE shall prepare and submit the final report when all sections of the report are 100% complete and all comments from the interim submittal have been resolved. The AE shall submit the Scope of Work for the study and any modifications to the Scope of Work as an appendix to the submittal. The report shall contain a narrative summary of conclusions and recommendations, together with all raw and supporting data, methods used, and sources of information. The report shall integrate all aspects of the study. The recommended projects, as determined in accordance with paragraph 5, shall be presented in order of priority by SIR. The lists of ECOs specified in paragraph 7.5.1 shall also be included for continuity. The final report and all appendices shall be bound in standard three-ring binders which will allow repeated disassembly and reassembly. The final report shall be arranged to include:

a. An Executive Summary to give a brief overview of what was accomplished and the results of this study using graphs, tables and charts as much as possible (See Annex B for minimum requirements).

b. The narrative report describing the problem to be studied, the approach to be used, and the results of this study.

c. Documentation for the recommended projects (includes LCCA Summary Sheets).

d. Appendices to include as a minimum:

1) Energy cost development and backup data
2) Detailed calculations
3) Cost estimates
4) Computer printouts (where applicable)
5) Scope of Work

ANNEX A

DETAILED SCOPE OF WORK

1. The facilities to be studied in this contract are used for the production of nitric acid in Area B at Holston Army Ammunition Plant (HSAAP) in Kingsport, Tennessee. Holston Army Ammunition Plant is a government-owned, contractor-operated (GOCO) facility. The operating contractor is the Holston Defense Corporation (HDC). For reasons of safety and security, access to the plant is controlled. Temporary passes will be required for both personnel and vehicle access.

a. A one-week notice should be given by the AE prior to any visit. This time will be needed to make the necessary arrangements for the visit.

b. The AE should submit a list of the equipment and instruments they plan to use prior to their arrival. Because of the nature of HSAAP operations, safety regulations prohibit and restrict the use of some equipment on the installation. Having a list of the equipment to be used beforehand, HSAAP will be better prepared at the entrance interview to address the regulations pertaining to the equipment to be used. This will also facilitate coordination of the inspection and permitting of the equipment.

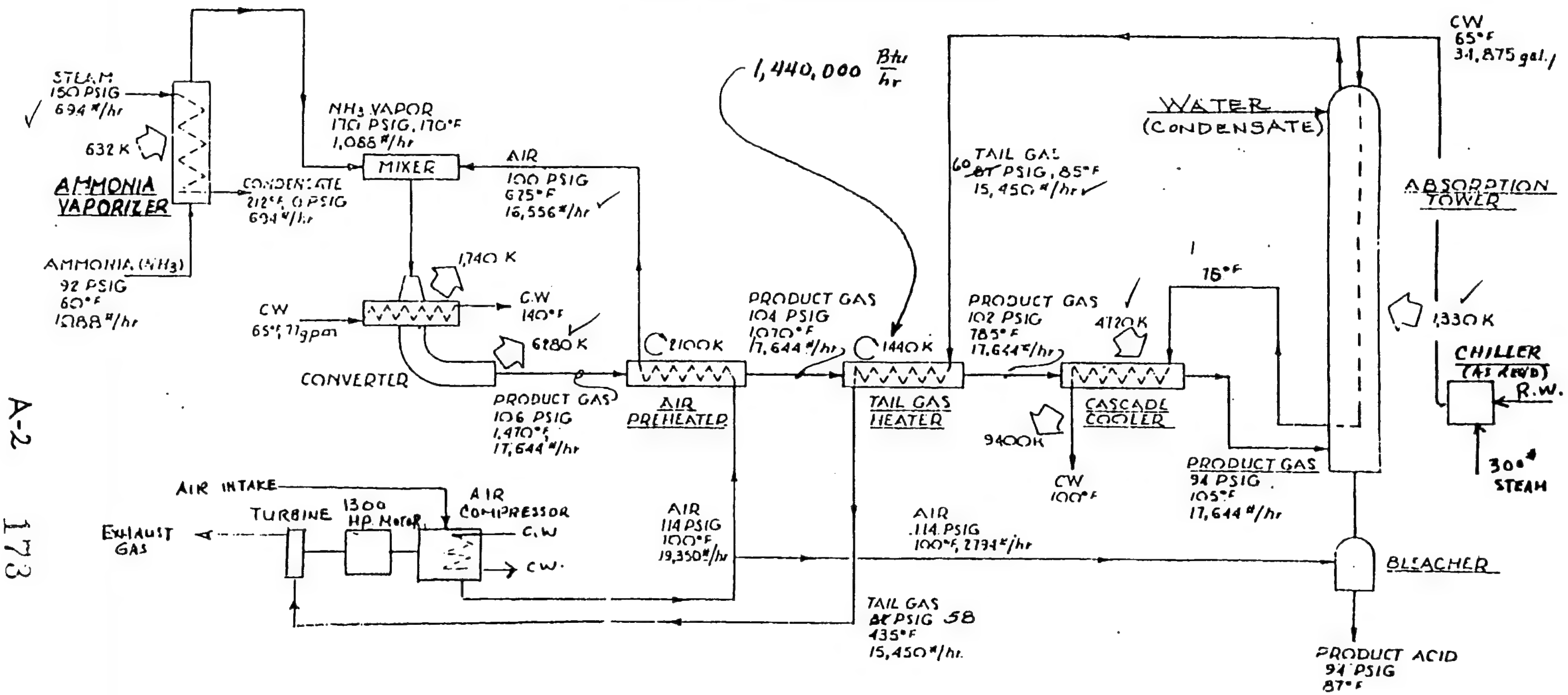
2. The following persons have been designated as points of contact and liaison for all work required under this contract. Mr. Scott Shelton shall be the Installation Representative, and Mr. J. L. Bouchillon shall be the Operating Contractor's Representative.

3. Completion and Payment Schedule: The following schedule shall be used as a guide in approving payments on this contract. The final report for this study shall be due not later than 180 days after Notice to Proceed.

MILESTONE	PERCENT OF CONTRACT AMOUNT AUTHORIZED FOR PAYMENT
Completion of Field Work	25
Receipt of Interim Submittal	75
Completion of Interim Presentation & Review	85
Receipt of Final Report	100

4. Purpose and Background: The purpose of this study is to identify and evaluate Energy Conservation Opportunities (ECOs) for the Ammonia Oxidation Process (AOP), which produces weak nitric acid. Figure 16 on page A-2 illustrates the AOP process. The chemical reactions utilized in the AOP are exothermic, producing large quantities of hot gases. Large amounts of cooling water are also used to cool and condense water vapor in the gases. Electrical energy is used to compress air for the process. Some heat and mechanical energy are already recovered

ENERGY BALANCE-BLDG. 302-B
NITRIC ACID MANUFACTURING



AS BUILT JAN 1995

HOLSTON ARMY AMMUNITION PLANT HOLSTON DEFENSE CORPORATION KINGSPORT, TENN. BLDG. 302-B, NITRIC ACID MFG.	DRAWN-PB DATE-2-14-76 APP'D- SK# 2286

FIGURE 16

in the process. However, there appears to be room for improvement in the process or by using recovered heat in nearby facilities. Building 302-B houses four 50-ton/day AOP units. Each AOP unit has an air compressor, which is driven by a 1300 HP electric motor. The motor is assisted by a gas turbine, which is driven by the tail gas from the process. At the present production level, one 50-TPD unit operates four continuous 24-hour days twice per month.

5. The AE is encouraged to propose and analyze any ECOs which he believes may save energy, water, or dollars. The AE must become familiar with the process and with the capabilities and limitations of the existing equipment. Due to the limited resources available, proposed ECOs should not impose additional maintenance and operation requirements. In addition to ECOs proposed by the AE, the following ECOs will be evaluated:

a. Since 300 psig steam is available, revise air compressor turbine drive to steam. There may be variations on this ECO, such as using 300 psig steam exclusively (which might require a different turbine) or using steam (at 300 psig or at a reduced pressure) in the existing turbine to assist the electric motor.

b. Use the product gas leaving the Air Preheater (Fig 16) to generate steam. Depending on the pressure of the steam generated, the gas could be cooled to perhaps as low as 400 degF. The steam thus generated could be used to drive (or assist in driving) the air compressor, or it could be used to vaporize ammonia, or for heating at the 302-B tank farm.

c. Identify and evaluate the possibility of water conservation at the cascade coolers and at other points in the process.

6. Government-furnished information. The following documents will be furnished to the AE:

a. Energy Conservation Investment Program (ECIP) Guidance, dated 10 Jan 1994 and the latest revision with current energy prices and discount factors for life cycle cost analysis.

b. AR 415-15, 1 Jan 84, Military Construction, Army (MCA) Program Development

c. TM5-800-2, Cost Estimates, Military Construction.

d. Tri-Service Military Construction Program (MCP) Index, dated day/month/year.

e. As-built drawings and process descriptions with quantitative data for the AOP facilities.

8. A computer program titled Life Cycle Costing in Design (LCCID) is available from the BLAST Support Office in Urbana, Illinois for a nominal fee. This computer program can be used for performing the economic calculations for ECIP and non-ECIP ECOs. The AE is encouraged to obtain and use this computer program. The BLAST Support Office can be contacted at 144 Mechanical Engineering Building, 1206 West Green Street, Urbana, Illinois 61801. The telephone number is (217) 333-3977 or (800) 842-5278.

9. Direct Distribution of Submittals. The AE shall make direct distribution of correspondence, minutes, report submittals, and responses to comments as indicated by the following schedule:

AGENCY	EXECUTIVE SUMMARIES	REPORTS	FIELD NOTES	CORRESPONDENCE
Holston Army Ammunition Plant ATTN: SMCHO-EN (Mr Shelton) Kingsport, TN 37660-9982	3	3	1**	1
US AMC I & SA ATTN: AMXEN-C (Mr Nache) Rock Island, IL, 61299-7190	1	1	-	-
Commander US Army Corps of Engineers ATTN: CEMP-ET (Mr Gentil) 20 Massachusetts Avenue NW Washington, DC, 20314-1000	1*	-	-	-
USAED, South Atlantic ATTN: CESAD-EN-TE (Mr Baggette) 77 Forsyth Street, SW Atlanta, GA 30335-6801	1	1	-	-
USAED, Mobile ATTN: CESAM-EN-DM (Battaglia) PO Box 2288 Mobile, AL 36628-0001	2	2	1**	1
US Army Logistics Evaluation Agency ATTN: LOEA-PL (Mr Keath) New Cumberland Army Depot New Cumberland, PA, 17070 - 5007	1*	-	-	-

* Receives Executive Summary of final report only.
** Field Notes submitted in final form at interim submittal.

ANNEX B

EXECUTIVE SUMMARY GUIDELINE

1. Introduction.

2. Building Data (types, number of similar buildings, sizes, etc.)

3. Present Energy Consumption of Buildings or Systems Studied.

   o Total Annual Energy Used.

   o Source Energy Consumption.

Electricity	- KWH, Dollars, MBTU
Coal	- TONS, Dollars, MBTU, MWH
Natural Gas	- THERMS, Dollars, MBTU, MWH
Other	- QTY, Dollars, MBTU, MWH

4. Energy Conservation Analysis.

   o ECOs Investigated.

   o ECOs Recommended.

   o ECOs Rejected. (Provide economics or reasons)

   o ECIP Projects Developed. (Provide list)*

   o Non-ECIP Projects Developed. (Provide list)*

   o Operational or Policy Change Recommendations.

* Include the following data from the life cycle cost analysis summary sheet: the cost (construction plus SIOH), the annual energy savings (type and amount), the annual dollar savings, the SIR, the simple payback period and the analysis date.

6. Energy and Cost Savings.

   o Total Potential Energy Savings in MegaBTU per year (and MegaWattHr per year) and first year dollar savings.

   o Percentage of Energy Conserved.

   o Energy Use and Cost Before and After the Energy Conservation Opportunities are Implemented.

ANNEX C

REQUIRED DD FORM 1391 DATA

To facilitate ECIP project approval, the following supplemental data shall be provided:

a. In title block clearly identify projects as "ECIP."

b. Complete description of each item of work to be accomplished including quantity, square footage, etc.

c. A comprehensive list of buildings, zones, or areas including building numbers, square foot floor area, designated temporary or permanent, and usage (administration, patient treatment, etc.).

d. List references, and assumptions, and provide calculations to support dollar and energy savings, and indicate any added costs.

(1) If a specific building, zone, or area is used for sample calculations, identify building, zone or area, category, orientation, square footage, floor area, window and wall area for each exposure.

(2) Identify weather data source.

(3) Identify infiltration assumptions before and after improvements.

(4) Include source of expertise and demonstrate savings claimed. Identify any special or critical environmental conditions such as pressure relationships, exhaust or outside air quantities, temperatures, humidity, etc.

e. Claims for boiler efficiency improvements must identify data to support present properly adjusted boiler operation and future expected efficiency. If full replacement of boilers is indicated, explain rejection of alternatives such as replace burners, nonfunctioning controls, etc. Assessment of the complete existing installation is required to make accurate determinations of required retrofit actions.

f. Lighting retrofit projects must identify number and type of fixtures, and wattage of each fixture being deleted and installed. New lighting shall be only of the level to meet current criteria. Lamp changes in existing fixtures is not considered an ECIP type project.

g. An ECIP life cycle cost analysis summary sheet as shown in the ECIP Guidance shall be provided for the complete project and for each discrete part included in the project. The SIR is applicable to all segments of the project. Supporting documentation consisting of basic engineering and economic calculations showing how savings were determined shall be included.

h. The DD Form 1391 face sheet shall include, for the complete project, the annual dollar and MBTU (MWH) savings, SIR, simple amortization period and a statement attesting that all buildings and retrofit actions will be in active use throughout the amortization period.

i. The calendar year in which the cost was calculated shall be clearly shown on the DD Form 1391.

j. For each temporary building included in a project, separate documentation is required showing (1) a minimum 10-year continuing need, based on the installation's annual real property utilization survey, for active building retention after retrofit, (2) the specific retrofit action applicable and (3) an economic analysis supporting the specific retrofit.

k. Nonappropriated funded facilities will not be included in an ECIP project without an accompanying statement certifying that utility costs are not reimbursable.

l. Any requirements required by ECIP guidance dated 10 Jan 1994 and any revisions thereto. Note that unescalated costs/savings are to be used in the economic analyses.

m. The five digit category number for all ECIP projects except for Family Housing is 80000. The category code number for Family Housing projects is 71100.

MINUTES OF MEETINGS

Affiliated Engineers SE, Inc.
3300 SW Archer Road
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MEETING NOTES

HOLSTON AREA B ACID FACILITY STUDY Project	95094-00 Project #
KINGSPORT, TN City, State	December 1, 1995 Date
INTERIM REVIEW Type of Meeting	1 of 2 MAH Page Typist
11/30/95 Meeting Date	PDL Copies

Present	Representing
Tony Battaglia	US Army Corps of Engineers
Scott Shelton	Holston AAP
Jerry Bouchillon	HDC
Alex Fancher	HDC
Paul Little	AESE
Carl Osberg	AESE

The purpose of this meeting was to review the Interim Report and the following items were discussed.

1. Reviewed schematic flow diagram of process. Several corrections were noted.
2. AESE to revise energy inventory table and show sample calculations (pages 43-49).
3. ECO No. 1 - needs to be revised to reflect replacing of the existing tailgas turbine with a steam condensing turbine. Noise will be an issue to review if tail gas is going to be exhausted.
4. ECO No. 2 - correct steam output from 31,000 to 3,100 lbs/hr and review using steam to assist turbine.
5. AESE to create a new ECO utilizing insulated air preheater, tailgas heater and plantnium recovery filter, with a once through steam system to assist the turbines.
6. Look at possibility of eliminating/replacing cascade cooler.
7. Plantnium filter needs to be located prior to any waste heat boiler and cascade cooler.
8. Stainless steel needs to be 400 grade for any metals in contact with product gas. AESE to get price quotes from manufacturers for waste heat boiler.
9. Dowtherm A (eutectic mixture of Diphenyl Oxide and Diphenyl) is incompatible with the process if a leak were to occur, and is to be eliminated from consideration for an intermediate heat transfer fluid.
10. Utilizing a cooling tower will jeopardize Pollution Permits (ECO No. 3).
11. Existing chiller has capacity for operating only (2) units at once.
12. Add Conclusions and Recommendations to Executive Summary section of the report.

13. Starting turbine without tail gas uses 290 amps of electrical power when tail gas is added to turbine the electrical power drops to 220 amps.

14. AESE to investigate chiller revision from a direct-contact steam condenser to a steam surface condenser from which steam condensate can be recovered. Because chiller operates only 5 months out of year, evaluate production level at which this modification will qualify for ECIP.

The above constitutes the writer's understanding of the discussions of this meeting and conclusions reached. Corrections/errors should be noted to the writer within 5 working days.

By:

AFFILIATED ENGINEERS SE, INC.

Paul D. Little

FOR Carl L. Osberg, P.E.
Vice President

Affiliated Engineers SE, Inc.

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MEETING NOTES

HOLSTON AAP NITRIC ACID PRODUCTION FACILITY Project	95094-00 Project #
HOLSTON, TN City, State	August 22, 1995 Date
EXIT INTERVIEW Type of Meeting	1 of 1 — Page; DA — Typist
08/17/95 (AM) Meeting Date	Copies

Present	Representing
Scott Shelton	SMCHO-EN
Alex Francher	HDC
Carl Osberg	AESE
Paul Little	AESE

The purpose of this meeting was to review the items surveyed and discuss probable areas of energy conservation. The following items were discussed.

Nitric Acid manufacturing process was observed in operation with absorption column #9 operating. Each of the four air compressors were operating, but only one of the four was being loaded. It was noted that compressed air final stage after cooler does not have dewpoint control or other control strategy. The steam jet refrigerating unit was confirmed to utilize a steam surface condenser.

The above constitutes the writer's understanding of the discussions of this meeting and conclusions reached. Corrections/errors should be noted to the writer within 5 working days.

By,

Paul D. Little

Paul Little, P.E.
HVAC Project Engineer

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MEETING NOTES

HOLSTON AAP NITRIC ACID PRODUCTION FACILITY Project	95094-00 Project #
HOLSTON, TN City, State	July 11, 1995 Date
EXIT INTERVIEW Type of Meeting	1 of 1 — MAH Page — Typist
07/07/95 Meeting Date	CO Copies

Present	Representing
Scott Shelton	SMCHO-EN
Charlie Fowler	HDC - Engineering
Robert Barnes	AESE

The purpose of this meeting was to review the items surveyed and discuss probable areas of energy conservation. The following items were discussed.

1. Bob Barnes briefly reviewed the scope of work for this project. Some options available for saving energy, water or dollars for this project include:
   - Recover heat to generate steam or hot water to supplement or eliminate steam used to vaporize ammonia.
   - Recover heat to generate steam to be used to reduce existing steam used at chiller.
   - Reduce filtered riverwater used at cascade cooler by storing chilled water in a closed loop configuration.
   - Recover heat to generate steam to run turbine at air compressor to reduce electric motor use.
   - Recover hot condensate from vaporizer and/or chiller to be regenerated to steam with waste heat for use at vaporizer or chiller.
   - Use 300 psig or 150 psig steam from existing steam system to run a turbine at the air compressor to reduce or eliminate the electric motor usage.

2. Bob Barnes asked Mr. Fowler if there were any ideas for energy conservation which had been overlooked. Mr. Fowler was not aware of other potential energy saving concepts.

3. Mr. Fowler clarified the capacity of the steam jet chiller. The chiller was relocated from another process and is approximately sized to handle 2 AOP process streams and not 4 as originally estimated by AESE.

The above constitutes the writer's understanding of the discussions of this meeting and conclusions reached. Corrections/errors should be noted to the writer within 5 working days.

By:

AFFILIATED ENGINEERS SE, INC.

Robert A Barnes

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MEETING NOTES

HOLSTON AAP NITRIC ACID PRODUCTION FACILITY	95094-00
Project	Project #
HOLSTON, TN	July 11, 1995
City, State	Date
ENTRY INTERVIEW	1 of 1 — MAH
Type of Meeting	Page — Typist
07/05/95	CO
Meeting Date	Copies

Present	Representing
Scott Shelton	SMCHO-EN
Jerry Bouchillon	HDC
Alex Fancher	HDC
Mike Richarme	AESE
Carl Osberg	AESE
Robert Barnes	AESE

The purpose of this meeting was to have an entry interview and the following items were discussed.

1. Mr. Jerry Bouchillon inquired as to the type of data needed to be furnished by HDC. AESE personnel requested information regarding: compressor intercooler water flow: Pump flows; pump curves; motor data; chiller capacity; and chiller steam flow and pressure.

2. Alex Fancher stated that manuals were available by Dupont which had technical data on the AOP process which could contain information useful for this project. The manuals would be located during the AESE field investigation to be reviewed for useful information.

3. Jerry Bouchillon would provide AESE with the name of the stainless steel fabricator who provided equipment for this facility to be used for pricing and special fabrication information.

4. AESE would conduct the field investigation today 07/05/95 instead of the document review listed in the AESE agenda. This would allow Mike Richarme to become familiar with the AOP Facility so he could shorten his field investigation time and depart this evening.

5. Jerry Bouchillon advised that mechanical and electrical drawings of the AOP Facility were downstairs in the engineering plan room. AESE personnel were invited to look through the drawings for relevant information for this project.

The above constitutes the writer's understanding of the discussions of this meeting and conclusions reached. Corrections/errors should be noted to the writer within 5 working days.

By:

AFFILIATED ENGINEERS SE, INC.

Robert A Barnes

Robert A. Barnes, P.E.
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MEETING NOTES

HOLSTON AAP NITRIC ACID PRODUCTION FACILITY Project	95094-00 Project #
HOLSTON, TN City, State	May 1, 1995 Date
PRE-NEGOTIATIONS Type of Meeting	1 of 2 MAH Page Typist
04/26/95 Meeting Date	RB Copies

Present	Representing
Tony Battaglia	US Army Corps of Engineers
Jerry Bouchillon	HDC
Scott Shelton	SMCHO-EN
Bob Lowe	HDC
Robert Barnes	AESE
Carl Osberg	AESE

The purpose of this meeting was to review the project scope and the following items were discussed.

1. HDC is investigating purchasing 100 lb steam from Tennessee-Eastman.

2. Acid production facility operates only 2 to 4 days/month but runs continuous during the 2 to 4 days. Currently run two units during this period. Investigate running one unit all week vs two units for 2 to 4 days. Staffing of facility needs to be considered.

3. A more detailed schematic diagram of the system is needed to better understand the system.

4. Steam cost is $2.94/MBtu at present. Electrical cost is $.03412/kWH.

5. Nitric acid production process was invented in 1935 and has been active at Holston since 1942. A newer more efficient process is now available and is also active at Holston. A new 300 ton/day unit is presently in use at HDC.

6. A waste heat boiler is a possible option to generate steam to run the air compressors to reduce the electric motor energy use.

7. Alex Fancher is contact point at acid production facility.

8. A steam jet ejector.chiller is currently used to cool river water when water temperatures rise in the summer months.

9. Jerry Bouchillon to update flow diagram of process, provide P&I drawings of process, and provide air compressor curves. Data on turbines will be made available at entry interview.

10. Proposal to Corps may also include ideas/approach to project that is different than scope of work.

11. AESE to notify Corps prior to submitting proposal of any special consultants, testing, etc. that is going to be proposed.

The above constitutes the writer's understanding of the discussions of this meeting and conclusions reached. Corrections/errors should be noted to the writer within 5 working days.

By:

AFFILIATED ENGINEERS SE, INC.

Carl L. Osberg

Carl L. Osberg, P.E.
Vice President